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(71) Applicant(s)
GEC-Marconi Limited

(Incorporated in the United Kingdom)

The Grove, Warren Lane, STANMORE, Middlesex, HA7 4LY, United Kingdom

(72) Inventor(s)
Simon Howard Spencer

(74) Agent and/or Address for Service
J Waters
GEC Patent Department, Waterhouse Lane, CHELMSFORD, Essex, CM1 2QX, United Kingdom

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GB 2135853 A

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(54) Video cameras

(57) A camera producing colour video outputs may employ an image intensifier 5 and a monochrome CCD sensor 3. The scene is exposed through filters F_3, F_4 which each contain stripes of subtractive primary colours alternating with clear regions. The video is decoded using waveforms derived from a memory 15 which records the output of the sensor 3 when imaged on, for example, primary colours such as red and blue, producing trains of pulses which identify the spatial regions of each line corresponding to the spatial areas of the pattern on the sensor produced by the colour filters F_3, F_4, in order that actual scenes can be decoded using the stored waveforms, for example using sample and hold devices. A colour interference signal is generated in matrix addition circuitry to produce a luminance signal which has stripe visibility removed from it, permitting high resolution video signals to be obtained.

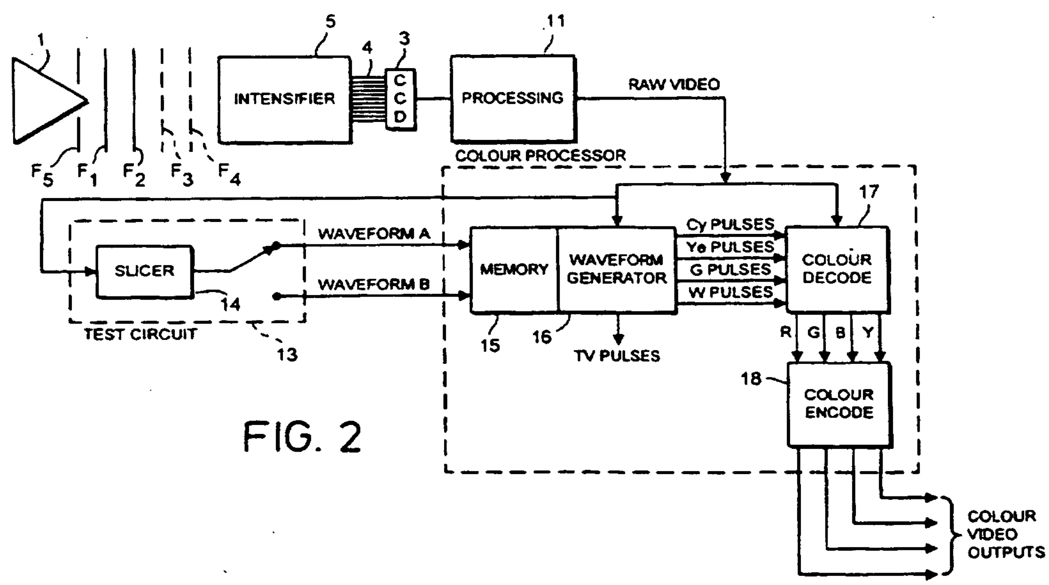

FIG. 2

GB 2 318 012 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

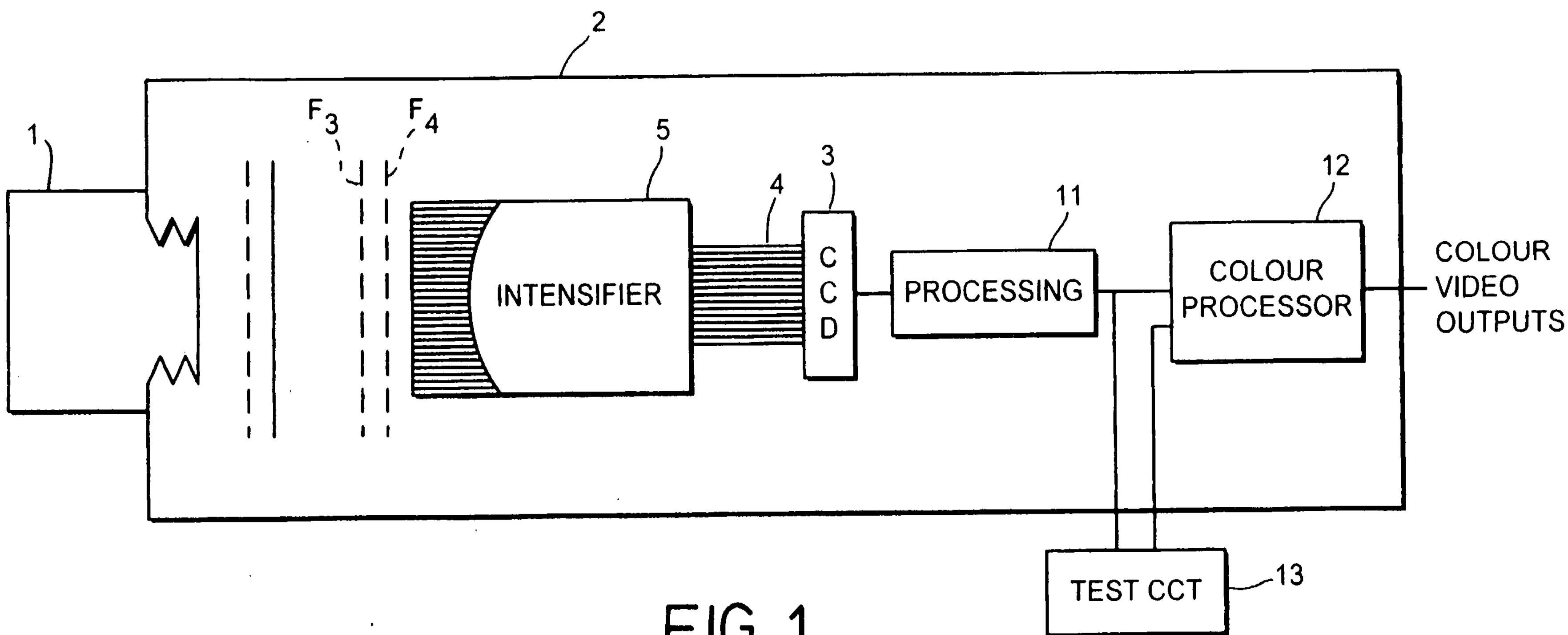
1
2
F3
F4
5
INTENSIFIER
4
3
C
C
D
11
PROCESSING
12
COLOUR
PROCESSOR
COLOUR
VIDEO
OUTPUTS
TEST CCT
13

FIG. 1

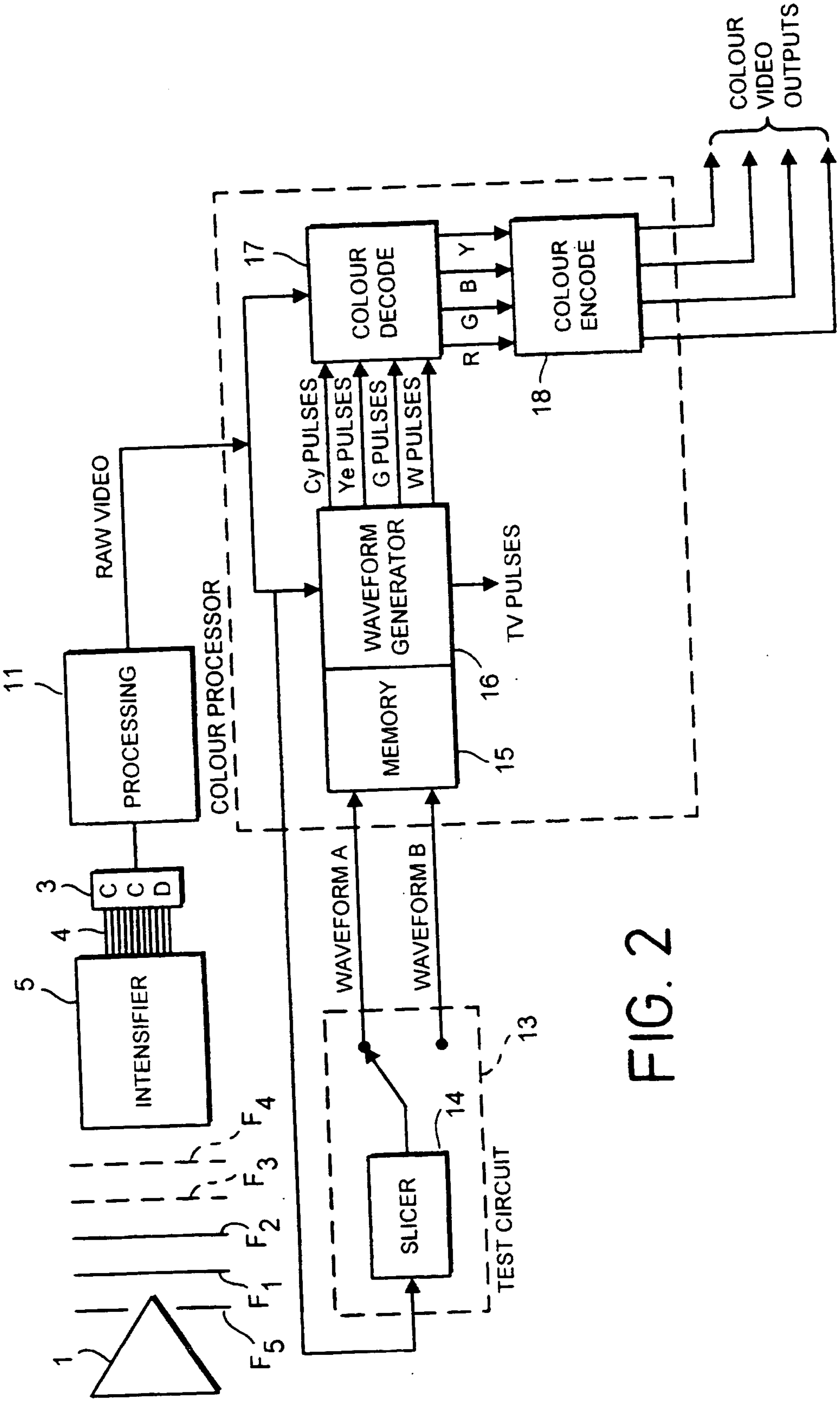
COLOUR VIDEO OUTPUTS
COLOUR DECODE
COLOUR ENCODE
17
18
R
G
B
Y
Cy PULSES
Ye PULSES
G PULSES
W PULSES
RAW VIDEO
WAVEFORM GENERATOR
TV PULSES
MEMORY
16
15
11
PROCESSING
COLOUR PROCESSOR
3
C C D
4
5
INTENSIFIER
WAVEFORM A
WAVEFORM B
13
14
SLICER
TEST CIRCUIT
F4
F3
F2
F1
F5
1

FIG. 2

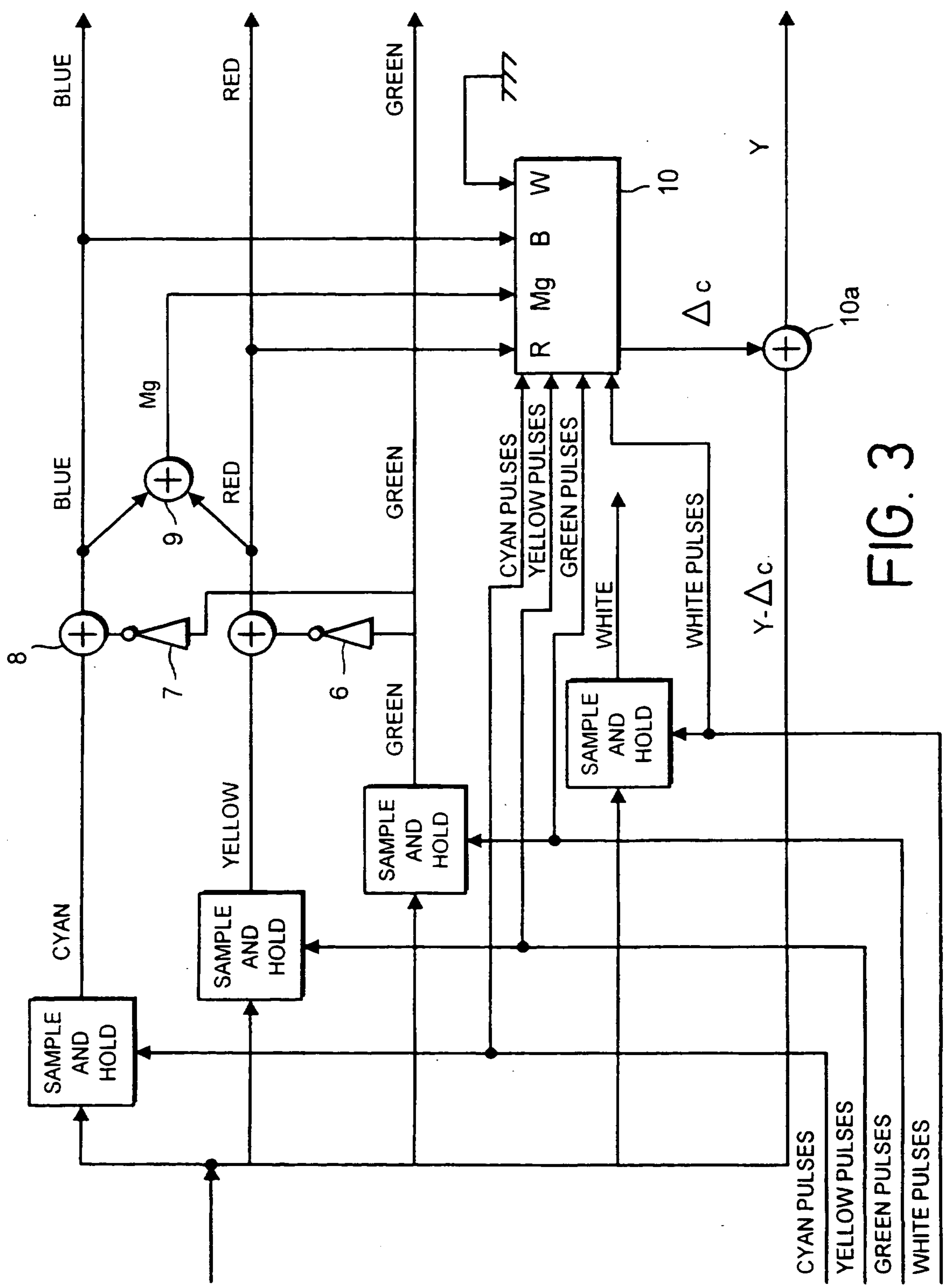
BLUE
RED
GREEN
W
B
Mg
R
10
Δc
10a
Y
BLUE
Mg
RED
GREEN
8
7
6
9
GREEN
CYAN PULSES
YELLOW PULSES
GREEN PULSES
WHITE
WHITE PULSES
Y-Δc
CYAN
YELLOW
SAMPLE AND HOLD
SAMPLE AND HOLD
SAMPLE AND HOLD
SAMPLE AND HOLD
CYAN PULSES
YELLOW PULSES
GREEN PULSES
WHITE PULSES

FIG. 3

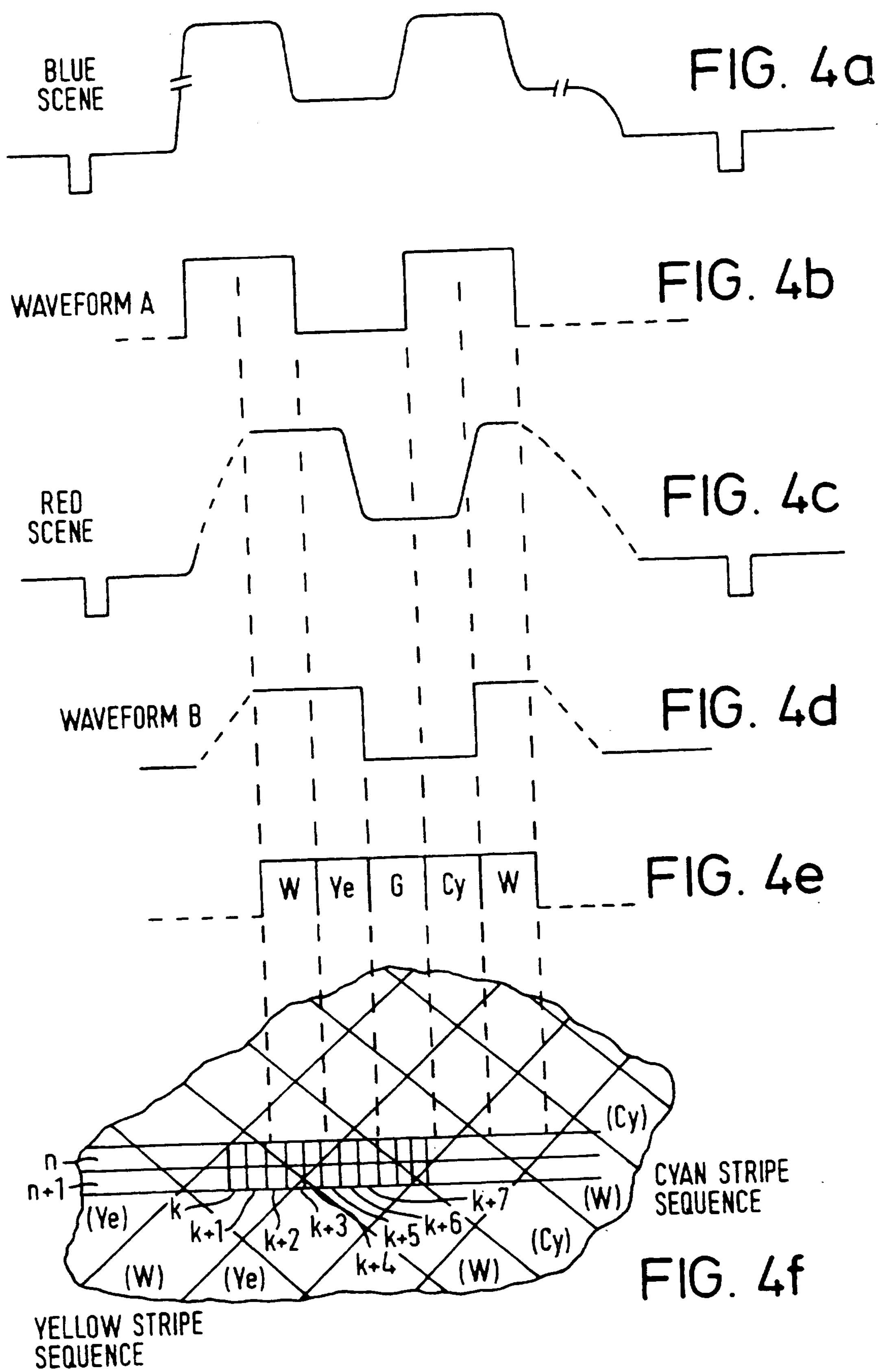

FIG. 4a

FIG. 4b

FIG. 4c

FIG. 4d

FIG. 4e

FIG. 4f

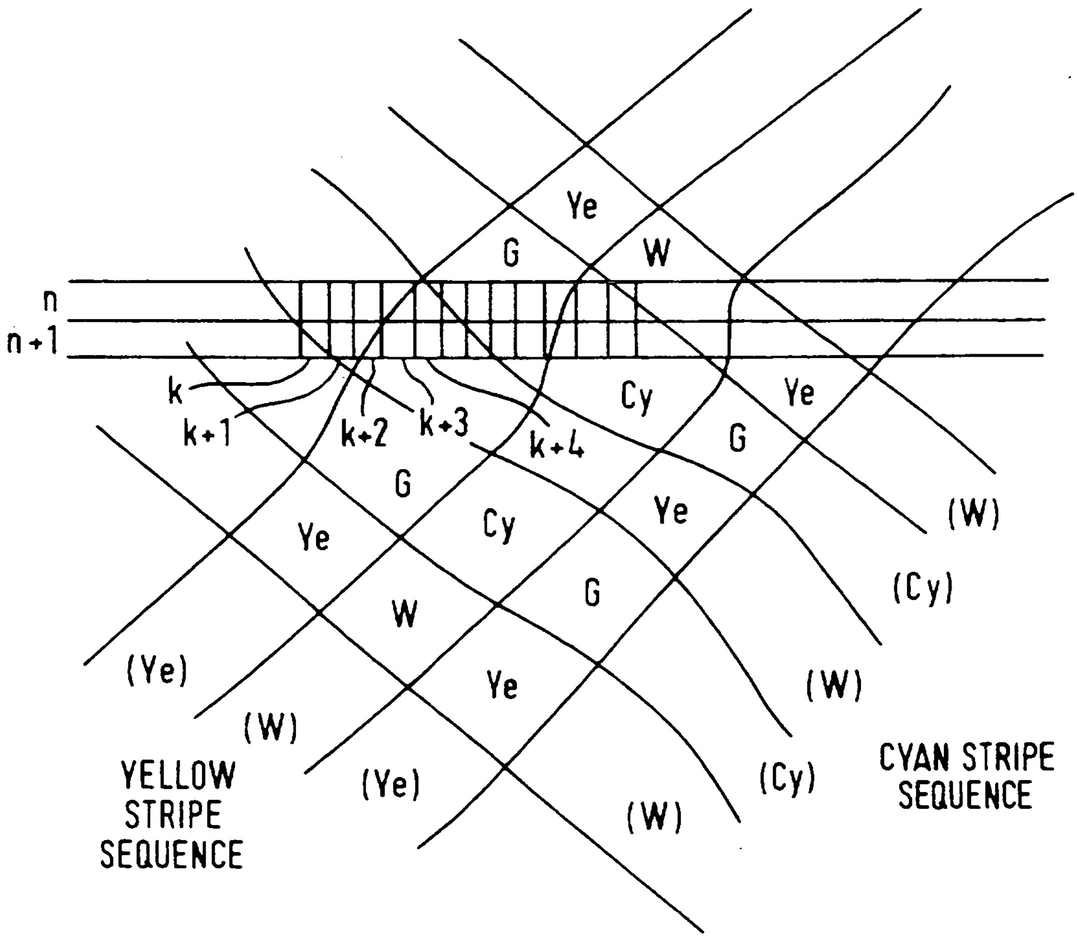
Ye
G
W
n
n+1
k
k+1
k+2
k+3
k+4
Cy
Ye
G
G
Cy
Ye
Ye
G
W
Ye
(W)
(Cy)
(W)
(Ye)
(W)
(Ye)
(Cy)
(W)
YELLOW STRIPE SEQUENCE
CYAN STRIPE SEQUENCE

FIG. 4g

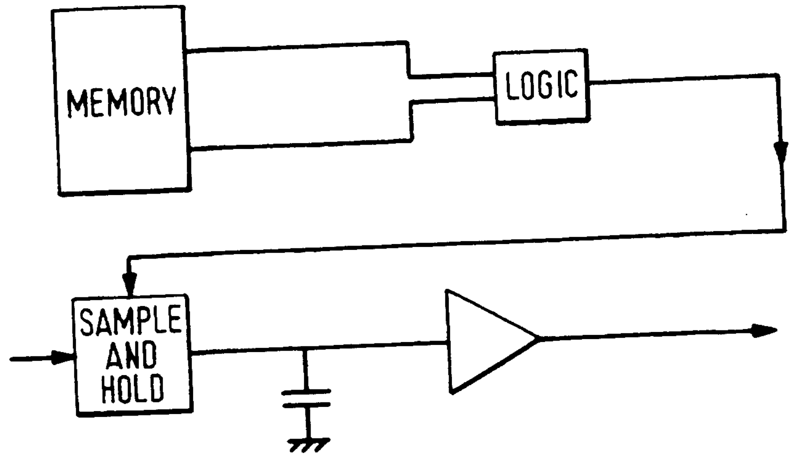

FIG. 5

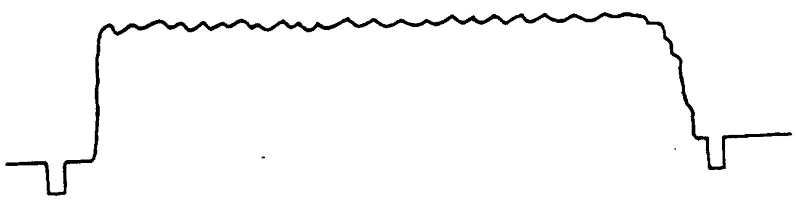

FIG. 6a

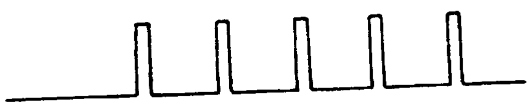

FIG. 6b

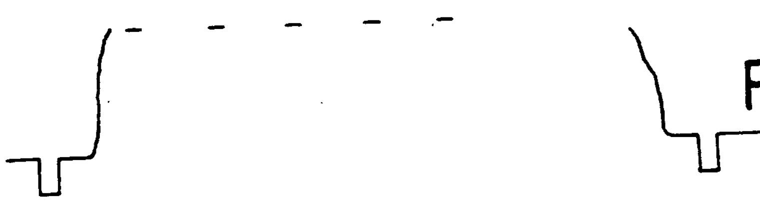

FIG. 6c

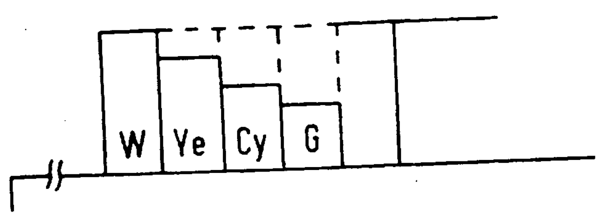

FIG. 7

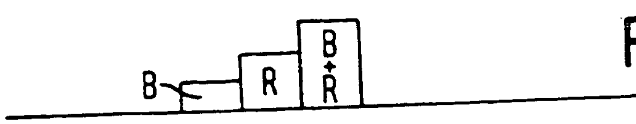

FIG. 8

CAMERAS

This invention relates to cameras.

The invention is particularly applicable to cameras which produce colour video outputs (including false colour) such as may be fed to a colour display.

The invention is also particularly applicable to such cameras in which a single radiation-sensitive sensor is used to produce the colour video outputs. Typically the sensor is scanned in a raster or sampled as in a solid state array.

Various proposals have been made to solve the problem of how to reproduce colours using a single sensor. One of the earliest proposals was Baird's system of aiming a monochrome television camera through a rotating filter, successive segments of which passed red, blue and green light. The receiver used a similar rotating filter synchronised with the one at the camera.

US-A-2 733 291 and US-A-3 378 633 disclose the concept of exposing monochrome light-sensitive devices (a vidicon in the case of the former and cine film in the case of the latter) to produce colour television outputs, each exposing the light-sensitive device through a filter consisting of stripes of two colours which repeat in the scanning direction at different frequencies. A tuned circuit is used to select the respective colour components in the output. In the latter patent, the filter consists of alternate clear and cyan vertical stripes, overlying alternate clear and yellow stripes inclined relative to the

vertical stripes. This provides a grouping of four elemental colour areas which is repeated over the entire area of the filter and is imaged over the entire area of each frame of the cine film. Where the transparent stripes overlap, the light-sensitive device produces a signal corresponding to the full luminance signal. Where cyan (which passes green and blue light) overlaps yellow (which passes red and green light), only the green component of the scene is imaged. Where the cyan and yellow stripes overlap the transparent stripes, the light-sensitive device images the green and blue, and green and red components of the scene, respectively. It is sufficient for the repetition frequency of the yellow and cyan stripes in the direction in which the cine film is ultimately scanned in order to produce signals for a colour television receiver to be different (for example, by making one set of stripes vertical and the other set of dimensionally identical stripes inclined), for it to be possible to extract the components in the output of the scanned cine film by means of tuned circuits. Sufficient information is provided for a low resolution luminance component to be produced, in addition to three components corresponding to the primary colours (red, green and blue).

A disadvantage of the use of tuned circuits to extract the individual components in the output of the video waveform is that only modest pictures are produced due to cross-talk (cross-luma and cross-chroma).

When each cine frame is raster scanned in US-A-3 378 633, the grey scale value of successive pixels on each line corresponds to that for the respective colour components i.e. white, yellow, green, cyan, in a fixed sequence. It has been proposed (Albert Macovski - Spatial-Frequency Encoding Techniques Applied to a One-Tube Colour

Television Camera, IEEE Transactions on Broadcasting, Vol BC-16, No. 4, December 1970) to sample the grey scale of each pixel on each video line corresponding to the respective colour components, rather than to discriminate between the components using tuned circuits. However, geometrical errors resulting in indefinite registration between the filter and the cine film, and between the cine film and its scanner, would make it difficult to predict which colour components any group of pixels represents.

It may be noted that this disadvantage does not apply in a consumer video camera, in which successive pixels along each line of the solid state imager are covered by gelatine filters which are yellow, cyan, green or transparent, because the filters are physically secured to the imager in this case. This means that, say, the first pixel on line 1 represents the scene imaged through a yellow filter, and accordingly outputs of the imager corresponding to the respective colour components can be derived with certainty.

However, such an arrangement would not be possible if the sensor included an image intensifier. In this case the filters would have to be positioned in front of the image intensifier rather than in front of the solid state sensor, since the output of the image intensifier is itself monochrome.

The geometrical distortion produced by an image intensifier is such that it would be impossible to predict the colour sequence for each line of the solid state imager based upon the sequence of elemental colour areas in the filter.

In the case of a single-tube colour television image pick-up apparatus exposed through

a colour stripe filter, it has been proposed to compensate for non-linearity in the tube's deflection system by the use of a frame memory (GB-A-2 135 853). The frame memory stores video signals corresponding to illumination of the tube with primary colours. These stored signals are used to compensate for non-linearities in the image pick-up mode of the tube. However, the video signals, while corrected for non-linearities caused e.g. by drift, are nevertheless low resolution.

It has been proposed ("Interplex - A New Versatile Full Resolution Single-Tube Colour TV Camera System", M Koubek, IEEE Transactions on Broadcasting Vol BC-22 No 3 September 1976, pp 30-35) to produce a high resolution single-tube camera. This is done by deriving a luminance signal which occupies a substantial proportion of the video bandwidth. A single-tube camera is exposed through a colour stripe filter, and separate colour outputs are produced, as in GB-A-2 135 853. The output of the single-tube is such a luminance signal, but the problem is that the stripe pattern is superimposed, and drastic filtering has been used in the past to remove the effect of the stripes. Because GB-A-2 135 853 uses vertical stripes, the respective colour information appears in the video bandwidth in the form of harmonics of the line frequency (which contains luminance information) and hence there is no way of separating the chrominance information and the luminance information, necessitating severe filtering of the bandwidth to produce a luminance signal. Koubek, however, uses obliquely orientated stripes, so the chrominance information is interleaved with the harmonics of the line frequency in the video bandwidth, and a comb filter is used to separate the chrominance and luminance information. This results in a luminance signal which is free of the shading pattern of the filter and thus has a bandwidth commensurate with the video bandwidth. However, the system relies on

using a linear scan camera tube (i.e. good geometry). If the stripe pattern on the target became distorted, the bandwidth of the chrominance signals would increase and would no longer interleave the line harmonics.

It is an aim of the invention to permit high resolution colour video signals to be obtained using a single sensor, even if accompanied by an image intensifier, which would suffer from significant geometric distortion.

The invention provides a camera comprising a sensor for receiving radiation forming an image of a scene, filter means positioned in the path of radiation incident on the sensor, the filter means being arranged to pass different spectral regions in different spatial regions, so that different spatial regions of the sensor are exposed to radiation of different spectral regions, decoding means for producing separate outputs from the sensor corresponding to the different spectral regions, the decoding means being arranged to use stored signals derived from the sensor output corresponding to exposure of the sensor through the filter means by radiation of reference spectral regions, and a circuit for using the outputs corresponding to the different spectral regions to remove visibility of the different spectral regions from the sensor output, to permit high resolution to be attained.

In the case of visible radiation, the colour outputs are used to remove the filter pattern from the sensor output, thereby providing an improved bandwidth luminance signal. The storage of signals derived from the sensor output when illuminated by radiation of reference spectral regions enables the sensor output for an actual scene to be decoded accurately and avoids the need to predict which spatial areas of the sensor correspond to

which spectral regions based upon geometrical considerations as well as avoiding the need for tuned circuits.

The colour outputs must of course be reasonably free from luminance cross-talk. One way of achieving this is to use a stripe filter the lines of which are orientated obliquely to the lines of the image.

Of course, the invention is not restricted to visible radiation and extends, for example, to I-R radiation for thermal imaging as well. In the latter case, the colour components fed to the display could be for the same colour components as for a video camera, but could be arranged to correspond, by the use of suitable spectral filters, to particular infra-red frequency bands. In this case, the image would be a false colour image, but having two or more images corresponding to different infra-red frequency bands could make an object easier to identify if displayed as false colours.

Advantageously, the camera includes a waveform generator for generating pulses derived from the stored signals which are applied to sample and hold means which receive a signal derived from the sensor output. One sample and hold means may be provided for each spectral region. The stored signal may be square waveforms derived from the sensor output, for example, programmed into a memory used by the waveform generator.

The sensor may include a CCD array, each spatial region which corresponds to a different spectral region including at least one, preferably at least four pixels.

In the case of a stripe filter, for visible radiation, there could be two sets of stripes, for example, yellow alternating with clear inclined at an angle to one side of vertical, with the other set, for example, cyan alternating with clear, inclined at the same or different angle to the other side of vertical. The invention is particularly applicable to a sensor which includes an image intensifier, for example, in order to provide a genuine colour image of a night-time scene. However, the invention is also applicable to sensors which respond in the infra-red or ultra-violet, in which case the camera would generate a false colour output.

A camera constructed in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of the camera;

Figure 2 is a block circuit diagram of the camera;

Figure 3 is a block circuit diagram of the Colour Decode and Colour Encode of Figure 2;

Figure 4a represents the waveform of the sensor output for a part of one line when imaging a blue scene;

Figure 4b shows Waveform A, a square wave waveform derived from that of Figure 4a;

Figure 4c shows the waveform of the sensor output of a part of a line when the camera

is illuminated by a red scene;

Figure 4d shows Waveform B, a square wave waveform derived from the waveform of Figure 4c;

Figure 4e illustrates graphically how the individual colour components are obtained from waveforms A and B;

Figure 4f shows a fragment of the filter projected onto a fragment of the CCD array as if no distortion were to take place;

Figure 4g shows a fragment of the filter projected onto a fragment of the CCD array showing typical distortion;

Figure 5 shows the interconnection of the memory and Waveform Generator in more detail;

Figure 6a shows a line of video signal;

Figure 6b shows one of the waveforms generated by the waveform generator;

Figure 6c shows the output of the sample and hold when the waveform of Figure 6a is input and the scanning pulses of Figure 6b are applied; and

Figures 7 and 8 are colour bar charts discussed with reference to Figure 3.

Referring to Figures 1 and 2, the camera produces colour video outputs. The camera has a lens 1 mounted in a casing 2, which contains a sensor comprising a CCD array 3 coupled by optical fibres 4 to the phosphors on the output surface of an image intensifier 5 at the focal plane of which filter means F_3, F_4 is cemented (the position of the filters has been exploded for clarity in Figures 1 and 2), the front part of the image intensifier also including a fibre optic coupling. F_1 is a correction filter which converts the spectral response of the sensor (i.e. the intensifier) to nominally photopic. The output of the CCD 3 undergoes processing in circuit 11 to produce a raw video output and then subsequent colour processing in circuit 12 to produce colour video outputs.

The CCD 3 and the image intensifier 5 being electro-optic devices, the spatial pattern of the colours of the filter means F_3, F_4 imaged onto the CCD 3 will not change with age or temperature and remains fixed once the camera has been manufactured. The colour processing uses stored signals based upon the response of the sensor to reference colours. These signals are generated after manufacture of each camera by means of test circuit 13. Once the signals have been stored, the test circuit is disconnected and the camera needs no further adjustment. If the intensifier were to be replaced over the lifetime of the camera, the manufacturer would have to reconnect the test circuit to programme in new stored signals.

The CCD 3 is a solid state device in the form of an array, a certain number of pixels to each line and a certain number of lines in the array. The scene is imaged in normal video

fashion in frames, each consisting of two consecutive interlaced fields.

Referring to Figure 4f, a fragment of the filter means is illustrated. The filter F_3 consists of diagonal yellow (Ye) stripes, the width and the spacing of which are equal to each other. In other words, between the stripes the filter is transparent (indicated W for white in the drawings). The filter F_4 consists of similarly arranged cyan (Cy) stripes spaced by transparent stripes. When the two filters are superimposed, a repeating pattern of four elemental colours is formed, as in the prior arrangements noted earlier.

If no distortions were produced by the lens 1, filters F_1, F_2, image intensifier 5, and fibre optic couplings, the spatial pattern of Figure 4f would be projected onto the CCD array 3. For the purposes of explanation, fragments of two lines n, n+1 of the CCD array 3, beginning at pixel k for each line, are illustrated in Figure 4f, as if the camera had distortion-free optics.

For line n, the kth pixel receives light from the image which has passed through the cyan filter, and so does the $k+1^{th}$ pixel. The next pixel, the $k+2^{th}$ partly receives imaging light through the cyan filter, and partly receives light through the transparent (white) filter. The $k+3^{rd}$ and $k+4^{th}$ pixels receive imaging light through the transparent filter. The next pixel ($k+5^{th}$) receives imaging light partly through the transparent filter and partly through the yellow filter, while the next two pixels receive light through the yellow filter. The $k+8^{th}$ pixel receives light through the yellow filter, partly through the cyan plus yellow (=green) filter, and the next two pixels only receive the light through the green filter.

Ignoring the pixels which receive light through the transition between two filter areas, the pixels of the n^{th} line receive cyan, white, yellow and green, in a repeating sequence, as shown in Figure 4e. The effect of the pixels which receive light from two filter areas can be reduced by taking the average of two lines for each of the yellow cyan and green signals. For a hypothetical non-distorting arrangement, the sequence of colours regularly repeats.

For line n+1, the sequence of colours exposed on the pixels again regularly repeats, but the sequence is now different. The k^{th}, $k+1^{th}$ and $k+2^{th}$ pixels receive light from the scene exposed through a cyan filter, the next two pixels, the $k+3^{rd}$ and the $k+4^{th}$ lie at the intersection of four filters, while the next four receive light through the yellow filter. The sequence for row n+1 is cyan, yellow, green.

For each line, for this hypothetical situation of no distortion, the pixels of each line are illuminated by areas of light, the colour of which varies in a fixed repeating sequence.

In reality, distortions are introduced by the lens, filters F_1, F_2, image intensifier 5, and by the fibre optic couplings. The pattern of the filter F_3, F_4 actually projected onto the CCD array could in a typical example, be more like the pattern of Figure 4g. The kinks are a by-product of the use of optical fibres. Compared to the ideal pattern which would be projected by perfect optics, a real spatial region corresponding to a particular spectral region could be displaced by as much as 20 pixels along a line of 600 pixels.

It will be apparent that there will still be a unique sequence of colours through which

successive pixels of each line are illuminated, but that the sequence will now no longer be regularly repeating and that there is no way of predicting what the (irregular) sequence for each line will be.

The raw video consisting of consecutive lines of each field is decoded in the sense of identifying those parts of a line which correspond to the scene viewed through each one of the four colours by using stored signals which are representative of the raw video output when the regularly repeating stripes are illuminated with primary reference colours. Thus, referring to Figure 4a, the camera is first imaged on a uniform primary blue scene. Cyan, which is a combination of blue and green, will be transparent to the blue, whereas yellow, which consists of red and green light, does not pass blue light, and so the result will be (referring to Figure 4f) blue regions which extend diagonally from the top of the drawing to the left of the drawing interspersed with similarly inclined dark regions. The blue stripes will result in the approximate sinusoidal variation shown for the fragment of one line in Figure 4a. Illumination by a uniform red scene will result in red stripes extending diagonally from the top of Figure 4f to the right interspersed with opaque stripes. Again a sinusoidal pattern will be produced (Figure 4c), but out of phase with that for Figure 4a. The raw video will be cyclic at the spatial (electrical) frequency of the cyan filter.

The lines shown in Figure 4a, 4c correspond to the hypothetical distortionless case for simplicity. With the actual pattern imaged on the CCD array, the traces Figure 4a and 4c will not be regular.

For each of the reference illuminations, the raw video from the CCD 3 is stored for a complete frame. What happens is that the approximately sinusoidal modulation passes through a slicer circuit 14 which produces waveform A from Figure 4a and waveform B from Figure 4c. These two waveforms are programmed into a memory 15 in the camera, each for a complete frame. The waveform generator 16 employs combinational logic on waveforms 4a and 4b to produce four waveforms, each containing just the pulses corresponding to one of the four colours i.e. yellow, green, cyan or white (Figure 4e). For example, logic "and" produces the pulses corresponding to white illumination, logic "not-or" produces an output corresponding to green illumination, and so on. Thus, the memory contains, for each line of each frame, pulse trains which indicate the precise points in time at which the raw video corresponds to illumination by the respective colour. The memory may be a preprogrammed memory i.e. PROM or EPROM (which selects parts of the waveform according to spatial location). This is used then to separate out the colour components from the raw video from an actual scene.

Referring to Figure 5, 6a to 6c, the raw video for one particular colour of the actual scene enters the sample and hold, which is controlled by pulses for that colour which are generated by the waveform generator using combinational logic from waveforms A and B in the memory. One line of the scene may be as shown in Figure 6a and the pulses which occur at the times when that line of the CCD are illuminated by one of the four colours shown in Figure 6b. The output of the sample and hold is as illustrated schematically in Figure 6c.

Referring to Figure 3, the same is done for each of the four colour components, resulting

in video waveforms corresponding to illumination through the cyan, yellow, green and transparent areas of the filter means. These four waveforms, from a non-volatile memory, will be produced every time the camera is operational. These are used to generate red, green, blue and luminance signals by matrix addition circuitry. Thus, inverter 6 and adder 7 subtract the green component from the yellow component, producing a red component. Inverter 6 and adder 8 subtract the green component from the cyan component to produce a blue component. At adder 9 the blue and red components are added to produce a magenta component. In addition circuit 10 the red, magenta and blue components are suitably added together to produce the colour interference component Δc. The white component need not be used.

The reason for the addition of the colour interference component may be seen from Figures 7 and 8. If one imagines a colour bar chart for any particular line of the video where the successive bars are produced by imaging through the transparent, yellow, cyan and green filter areas, the overall intensity of the yellow, cyan and green areas is clearly less than that of the white areas, since the yellow area has subtracted blue, the cyan area has subtracted red, and the green areas have subtracted blue and red. The correct proportions for the red and blue are produced in circuit 10 to produce the corrected high resolution luminance signal Y at adder 10a. The low resolution luminance signal leaving box 11 (Processing) would represent the grey scale intensity of the scene, but would have the stripe pattern visible on it, forming a pattern as in Fig 4g, but with various grey levels for the cyan, yellow and green areas. The matrix addition circuitry 10 removes the visibility of this stripe pattern from the raw video signal, producing a luminance signal having a bandwidth occupying a significant proportion of the video bandwidth.

The matrix addition circuitry 10 is gated by the cyan, yellow and green pulses to produce the appropriate Δc for the appropriate part of the raw video waveform. Thus, at the times (Fig 6c) when the sample and holds produce an output for one particular colour, say, for green, Δc is added to the raw video at those instants to reflect the fact that the raw video is considerably reduced in intensity because the red and blue components have been stopped. The same happens at the instants at which the sample and holds for other colours produce outputs as shown in Fig 6c. Clearly, Δc is zero when the white pulses arrive at the matrix addition circuitry. The action of the sample and hold circuits convert the incoming modulated waveforms into continuous waveform components of cyan, yellow and green without any discontinuities (i.e. gaps). The action of the adders 6, 7 produces the full set of primary signals, red, blue (and green), which are also continuous waveforms.

It should be added that the addition performed at adders 8, 9 and inverters 6, 7 produces primary colours which do not have luminance cross-talk. This is made possible by the non-vertical nature of the stripes.

The matrix addition circuitry 10 may include a clipping circuit to restrict Δc to 30% input white (Y) level at times when cyan is subtracted. Then if a noise spike is generated in the matrix addition circuitry 10, the noise spike is limited. Similarly, Δc can be restricted to 10% (of Y) at times when yellow is subtracted (see Figures 7 and 8).

The corrected luminance signal may be further improved by passage through a comb filter to remove residual colour energy. The luminance comb "stop bands" occur at frequency

locations which are in between line harmonics. These locations depend on stripe angle and geometry errors. The benefit of the colour separation technique described is that significant suppression is achieved with poor geometry sensors. Further inclusion of a comb filter enables even better suppression and reduction of noise (both random and static). Poor geometry sensors could not use comb filters without the colour separator herein described.

It is desirable that the camera used for producing colour should have the following features, crystal timing, unity gamma, and good modulation at the highest stripe spatial frequency (i.e. 50% at 3.7MHz).

The red, green, blue and luminance signals pass from the Colour Decode 17 into Colour Encode 18. Gamma correction is performed in this circuit, and a high pass filtered version of the luminance signal is added to each of the low resolution red, green and blue channels to produce three high resolution outputs (known as "mixed high" processing). The output of Colour Encode 18 is in three groups. The first group is three channels of red, green and blue video outputs together with synchronising waveforms. The second group is two channels of the luminance signal (Y) and the chrominance signal (C). The third group of channels is a single channel which is used to encode either PAL, NTSC or SECAM. Outgoing video from the decoder is T.V. standard encoded to suit external equipment (i.e. TV displays, video recording, r.f. links etc.).

The waveform generator 16 is also responsible for generating TV pulses such as synchronisation pulses, blanking pulses and clamping pulses etc.

A typical resolution of the CCD array could be around 600 pixels by 600 lines. For a conventional TV line frequency, which corresponds to a line period of 64μs and an active line period of 52μs, the maximum frequency which can be resolved along the lines would correspond to alternate black and white values i.e. 300 periods in 52μs i.e. a maximum frequency of around 6MHz. The response of the intensifier falls as the frequency increases and, for this reason, a typical frequency for, say, the cyan stripe is 3MHz. This would correspond to two pixels for the cyan stripes, alternating with two for the interposed transparent stripes. Along a line of an array with pixels of 20μ by 20μ, this would give a stripe frequency of 12½ line pairs per mm (referenced to the CCD array) i.e. there would be 12½ cyan stripes and 12½ interposed transparent stripes per mm. Remembering that the stripes are advantageously inclined, say, at 22° on either side of the vertical centre-line of the array, this would equate to an actual line spacing of around 15 line pairs per mm for both the cyan and yellow stripes.

Defocus filter F_2 reduces alias disturbance of scene detail, and may be a lenticule, birefringent plate, Savart plate or cylindrical lens. For surveillance use (i.e. long focal length lenses, zoom lenses etc) this filter can be omitted.

The shading errors of the intensifier are a fixed signature of the sensor and can thus be optically corrected. During camera manufacture, the shading errors can be measured (see the roll-off at the end of the line in Figure 4a), and an inverse profile pattern can be produced (by for example a computer line transparency printer). It is beneficial to perform shading correction opticaliy using filter F_5 rather than electronically as this avoids errors from scenes of low contrast.

It will be seen that the proposed system uses a technique which allows sampling extraction to derive colour waveforms. It is believed that this approach is superior to all other approaches as it enables poor performance cameras to be used.

The innovations are the method of deriving the sample patterns, the method of storing the sample patterns, the method of removing colour errors from luminance signals (i.e. Δc cancellation), the method of removing luma errors from chroma signals (i.e. colour separation) and the method to remove shading.

The technique has the following benefits: improved luma cross-talk i.e. the rejection of colour signals onto the luma channel will be constant over the total area of the picture; improved chroma cross-talk, the rejection of colour cross-talk of one colour onto another will be constant over the total picture area (colour shading will not arise or "constant luminance" will exist); the rejection performance will not degrade with either temperature or age (a feature of intensifiers); the technique can be implemented by totally digital techniques (i.e. low cost, small size and stable performance); the intensified colour pattern can be small in size, low on power and low cost; improved rejection can be achieved by adding further filtering by using one or two TV line comb filters; white highlights in the scene or dark parts of a scene will not be coloured "green" i.e. the system has a desirable "fade-to-grey" feature; choice of striped filters is not dependent upon compromising performance e.g. stripe angles could be ±45° for NTSC systems, ±22.5° for PAL systems or even between ±20° to ±30°. The pitch stripe frequency can be the same for both colours (cyan and yellow). This allows the stripe frequency to be low (e.g. 2.5 MHz), thereby allowing the use of poor resolution modulation transfer function sensors

such as intensifiers; the colour beat pattern i.e. frequency difference between colour filters will be hardly perceptible throughout the total picture area as the sample pulses are synchronised to the patterns - cameras with poor geometry performance (10%) can be used as the colour performance is not impaired by geometry; and colour errors caused by poor corner focussing (i.e. astigmatism) will be seen as lesser colour saturation rather than colour (hue) errors - the shading corrector (optical) lessens the saturation error. Examples of intensifier types for use with this technique are: first generation; second generation; or electron bombarded CCD. Intensifiers with a cover glass (e.g. third generation) can be used with a relay lens. The point here is that the focal plane lies within the casing of the intensifier making it impossible for the filter to be secured at this point. The relay lens puts the filter at the focus of the relay lens which is itself focuses at the focus of the intensifier. All sensors should have a linear transfer function i.e. unity gamma.

The camera is not limited to use with an intensifier, and could be used on a CCD without the intensifier. Further, types of solid state sensor other than CCD could be used.

While the description has been in relation to the use of cyan and yellow stripes, it would be possible to use any combination of two subtractive primary colours, or three subtractive primary colours could be used, possibly without the transparent regions, and primary colours themselves could be used, but this would reduce performance considerably. The reference illuminating colour would of course depend upon the colours in the filter. Other angles of the stripes and spacings could be used. Further, instead of having two sets of stripes inclined on each side of vertical, one set of stripes, for example, cyan, yellow, green and clear, or red, green and blue, inclined obliquely to the lines, could

be used. Also, patterns other than stripes could be used as circles, hexagons etc.

Finally, the invention is applicable to wavelengths outside the visible range, for example the infra-red range where the filters F_3 and F_4 will correspond to particular infra-red spectral regions in the way that the yellow and cyan stripes correspond to particular visible regions, resulting in a false colour picture where objects emitting in three different frequency ranges are separately shown.

CLAIMS

1. A camera comprising a sensor for receiving radiation forming an image of a scene, filter means positioned in the path of radiation incident on the sensor, the filter means being arranged to pass different spectral regions in different spatial regions, so that different spatial regions of the sensor are exposed to radiation of different spectral regions, decoding means for producing separate outputs from the sensor corresponding to the different spectral regions, the decoding means being arranged to use stored signals derived from the sensor output corresponding to exposure of the sensor through the filter means by radiation of reference spectral regions, and a circuit for using the outputs corresponding to the different spectral regions to remove visibility of the different spectral regions from the sensor output, to permit high resolution to be attained.

2. A camera as claimed in claim 1, including a waveform generator for generating pulses derived from the stored signals which are applied to sample and hold means which receive a signal derived from the sensor output.

3. A camera as claimed in claim 1 or claim 2, in which the stored signals are square waves derived from the sensor output.

4. A camera as claimed in any one of claims 1 to 3, in which the sensor is arranged to produce an output representative of lines of the image, and the filter means comprises stripes orientated obliquely to the lines of the image.

5. A camera as claimed in claim 4, in which the stripes are formed of two sets, one set comprising stripes passing one spectral region alternating with stripes passing all spectral regions of the sensor, and the second set comprising stripes passing another spectral region alternating with stripes passing all spectral regions of the sensor.

6. A camera as claimed in claim 5, in which the said one spectral region and the said other spectral region are subtractive primary colours, and the alternating stripes are clear.

7. A camera as claimed in claim 6, in which the subtractive primary colours are yellow and cyan.

8. A camera as claimed in any one of claims 5 to 7, in which the pitch of the stripes and the alternating regions are equal, and each set of stripes is inclined at an angle to the line direction.

9. A camera as claimed in any one of claims 5 to 8, in which the sets of stripes are inclined to different sides of a notional vertical line of the image.

10. A camera as claimed in any one of claims 1 to 9, in which the reference spectral regions are primary colours.

11. A camera as claimed in claim 5, in which the filter means lies at the image plane of the sensor or at the focus of a relay lens for the sensor.

12. A camera as claimed in any one of claims 1 to 11, in which the sensor includes an image intensifier.

13. A camera as claimed in claim 12, in which the sensor includes a solid state imager.

14. A camera as claimed in any one of claims 1 to 11, in which the sensor is an infra-red sensor.

15. A camera substantially as herein described with reference to the accompanying drawings.

The Patent Office

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Claims searched: 1 to 15

Examiner: John Donaldson
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Other: Online:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2135853 A (NIPPON VICTOR), see page 3, lines 16 to 63	-

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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(71) Applicant: I SIGHT, INC. [US/US]; 14 Ridgedale Avenue, Suite 125, Cedar Knolls, NJ 07927 (US).

(72) Inventors: GINOSAR, Ran; Nofit (IL). GENOSSAR, Tamar; 20 Fichman Street, Haifa (IL). ZINATY, Ofra; 16/12 Peretz Markish Street, Haifa (IL). SOREK, Noam; Kiryat Haroshet (IL). KLIGLER, Daniel, J.; Moshav Zippori (IL). ZEEVI, Yehoshua, Y.; 48 Alexander Yannai Street, Haifa (IL). NEYSHTADT, Arkadi; 86-5 Shoshanat Hacarmel Street, Haifa (IL). AVNI, Dov; 7 Sukkot Street, Haifa (IL).

(74) Agent: DIPPERT, William, H.; Cowan, Liebowitz & Latman, 605 Third Avenue, New York, NY 10158 (US).

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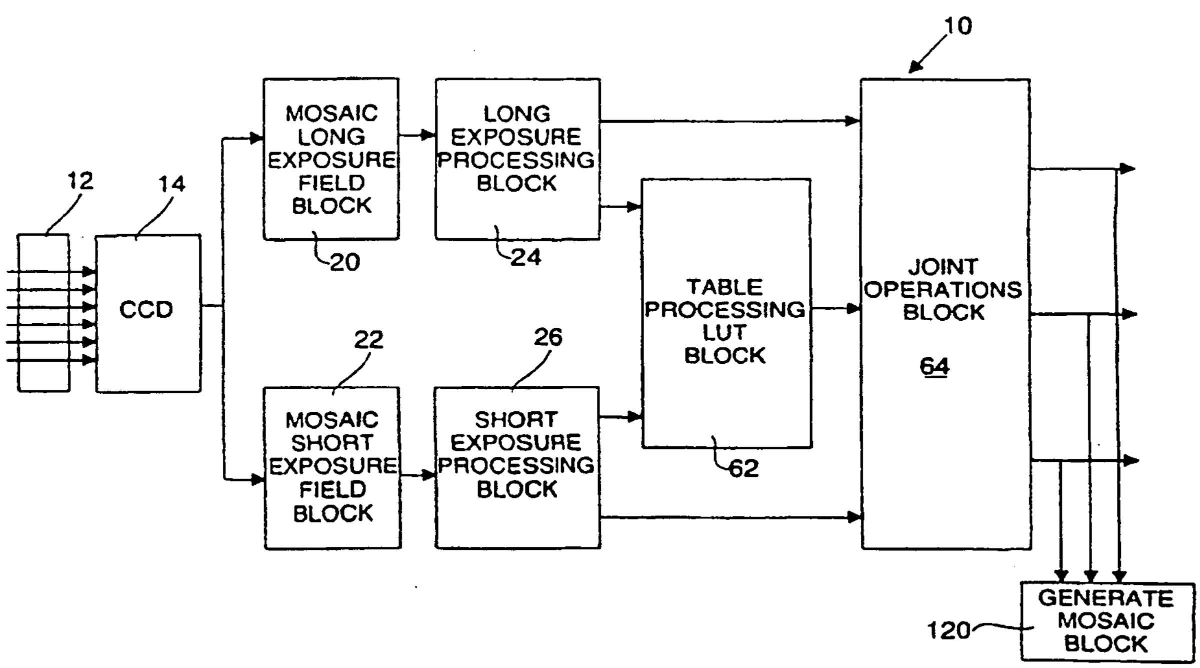

(57) Abstract

The apparatus (10) is a color wide dynamic range apparatus which includes a filter (12) interposed immediately in front of reoccurring color elements so that each pixel represents a given color element for the scene. At least two exposure levels are taken of the scene and the pixel outputs are decoded to generate the video luminance and chrominance signals. The images of the at least two exposure levels are combined to form a final image.

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COLOR WIDE DYNAMIC RANGE CAMERA USING A CHARGE COUPLED DEVICE WITH MOSAIC FILTER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. patent application Serial No. 07/795,350 filed November 20, 1991 entitled "Color Wide Dynamic Range Camera", which is, in turn, a continuation-in-part of U.S. patent application Serial No. 07/388,547, filed August 23, 1989, now U.S. Patent No. 5,114,442. Additionally, this application is related to U.S. Patent No. 4,858,014 and currently pending U.S. patent application Serial No. 07/805,512, filed December 11, 1991. The disclosures of all of the above-identified U.S. patents and patent applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

This invention pertains to video imagery and more particularly to apparatuses and techniques for providing enhancement of video color images. In particular, the present invention uses a four-color mosaic filter with a single chip CCD in conjunction with color wide dynamic range algorithms. It is also applicable, however, to other types of mosaic filters known in the art.

Description of the Prior Art

Various types of video enhancement apparatuses and techniques have been proposed. Prior implementations of color wide dynamic range cameras, such as those disclosed in the above-identified parent applications hereto, have used a plurality of CCD chips to generate the image data for subsequent processing. The use of multiple CCD chips, however, adds to the complexity and cost of the instrument. Moreover, current consumer video cameras, i.e., camcorders, almost universally use a single CCD chip. Therefore, a single CCD implementation is required to use dynamic range enhancement algorithms in a camcorder. Single CCD chip implementations are similarly preferred for endoscopic applications.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a color wide dynamic range camera implemented with a single CCD chip.

It is also an object of this invention to provide a color wide dynamic range camera which is adapted for use with a camcorder.

It is a further object of this invention to provide a color wide dynamic range camera which is adapted for use with a conventional endoscope.

These and other objects of the invention will be more apparent from the discussion below.

SUMMARY OF THE INVENTION

There is thus provided in accordance with the preferred embodiment of the present invention, video imaging apparatus including means for providing a plurality of video color images of a scene at different exposure levels using a single CCD chip, each color image being separated into several (e.g., four in the preferred

embodiment) different components prior to sensing by the CCD chip by way of a multiple color mosaic filter in front of the CCD chip. The pixel outputs are then decoded -- subjected to specific mathematical operations by the processing electronics following the CCD output -- to generate the video luminance and chrominance signals.

The present invention integrates the digital processing of the mosaic color CCD data with ADAPTIVE SENSITIVITY™ dynamic range enhancement. This integration provides for a substantial savings in total system processing hardware chip count and cost. It also permits better control of the color and detail production of the camera's video output. The mosaic storage format also provides for a unique video image compression technique.

BRIEF DESCRIPTION OF THE DRAWINGS

Further objects and advantages of the invention will become apparent from the following description and claims, and from the accompanying drawings, wherein:

Figure 1 is a general block diagram of the present invention.

Figure 2 is a representative illustration of the data image elements, with the size of the data image elements exaggerated.

Figure 3 is a general block diagram of the long and short processing of the present invention.

Figure 4 is a block diagram of the color path of the present invention.

Figure 5 is a block diagram of the intensity path of the present invention.

Figure 6 is a block diagram of the look-up table processing of the present invention.

Figure 7 is a block diagram of the joint operations of the present invention.

Figure 8 is a block diagram of the differential color, intensity result block of the present invention.

Figure 9 is a block diagram of the color suppression factor block of the present invention.

Figure 10 is a block diagram of the color conversion block of the present invention.

Figure 11 is a block diagram of the mosaic generation block of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings in detail wherein like numerals indicate like elements throughout the several views, one sees that Figure 1 is a block diagram of the apparatus 10 of the present invention.

Apparatus 10 includes a mosaic filter 12 which is bonded to the front of CCD 14 (preferably a single chip), generally as part of the CCD integrated circuit manufacturing process.

The alternating mosaic filter elements are cyan, magenta, yellow and green (wherein C 'cyan' = G 'green' + B 'blue'; M 'magenta' = R 'red' + B; and Ye 'yellow' = R+G). When the CCD 14 charge output is read out, the photoelectric charges from vertically adjacent sensor elements of CCD 14 are combined in the analog shift register (not shown). The on-chip addition gives rise to α, β, γ and δ elements as described below and as described in the Sony CCD 1992 Data Book (Sony part number ICX038AK), as well as earlier editions.

As shown in Figure 2, the mosaic complementary additive color image comprises alternating first and second rows of image data elements 18_A — 18_D wherein first rows include alternating α and γ data elements (18_A and 18_B, respectively), and wherein the second rows include alternating β and δ data elements (18_C and 18_D, respectively).

The α image data elements 18_A are an equal mixture of cyan plus green (i.e., C + G = B 'blue' + 2G 'green'). The γ image data elements 18_B are an equal mixture of magenta plus yellow (i.e., M + Ye = 2R 'red' + B + G). Similarly, the β image data elements 18_C are an equal mixture of cyan plus magenta (i.e., C + M = 2B + G + R) and the δ image data elements 18_D are an equal mixture of green plus yellow (i.e., G + Ye = 2G + R).

Those skilled in the art will recognize that:

$$Y \text{ (i.e., intensity)} = \frac{\alpha + \gamma}{2} = \frac{\beta + \delta}{2}$$

from which the definition of intensity (Y) in the red, green, blue (RGB) system may be derived:

$$Y = R + 1.5G + B$$

Of course, those skilled in the art will realize that other color combinations are equally applicable. Each mosaic element of filter 12 covers the sum of two adjacent pixel sensors of CCD 14 so that each pixel output of CCD 14 is representative of one of the above color combinations given for the various image data elements 18. Four different monochromatic images, each representative of one color combination chosen from the colors of image data elements 18_A - 18_D of a given scene, are therefore generated by CCD 14.

As can be further seen from Figure 1, apparatus 10 includes four major functions as summarized below:

1. Long/short exposure processing:

   The first stages of the algorithm are performed on the two exposures (long/short) separately. The processing of each exposure is divided into two paths:

   a. Color path processing - evaluates color component for each pixel.

   b. Intensity (Y) path processing - handles intensity information for each pixel. This includes point ("DC") intensity and edge information.

2. Point prccessing:

   Each of the long/short exposure length processing functions (typically implemented on separate chips) outputs its point intensity information, obtained from the Y path processing, to four look-up tables (LUTs). These tables determine the point intensity result of the two exposures, the normalized color weighting or color selection function and the saturation color suppression factor. This information serves the joint operation processing stage. The four LUTs are programmable, thus enabling operation with different functions when necessary. In an alternative embodiment, these LUTs may be replaced by a programmable, piecewise linear (PWL) or other digital function generator.

3. Joint operations processing:

   Joint operations processing joins results produced by the long and short processing blocks, and results obtained from the functions implemented in the table processing LUTs, and evaluates the final output of the algorithm. The processing is divided into:

   a. Color components and Y result calculation — evaluates the final result of the color components and the intensity of each pixel.

   b. Color suppression factor calculation — evaluates the color suppression factor for each pixel, based on both edges and saturation information.

   c. Color conversion processing — converts mosaic differential color space to RGB color space and produces RGB and Y/Cr/Cb outputs for each pixel.

4. Generate mosaic processing.

   Generate Mosaic processing converts RGB color space back to mosaic color space for each pixel. The mosaic information generated enables economical hardware storage of processed images. This information can be retrieved and replayed through the algorithm — in

Replay Mode — to produce RGB or Y/Cr/Cb output of the stored result.

Referring now to Figure 1, similar to U.S. Patent No. 5,144,442 and parent U.S. patent application Serial No. 07/795,350 (the disclosures of which, again, along with U.S. patent application Serial No. 07/805,512 and U.S. Patent No. 4,858,014 are incorporated herein by reference), apparatus 10 includes long/short processing as implemented by mosaic long exposure field block 20 and mosaic short exposure field block 22 which obtain, respectively, a long and a short exposure from CCD 14 in order to allow subsequent processing by long exposure processing block 24 and short exposure processing block 26. The terms "long" and "short" exposures are used here generally to denote two image inputs to apparatus 10. In general, "long" is used to mean an input with a higher exposure level, and "short", a lower exposure level. The higher exposure may be generated in several ways, including longer integration time, typically obtained by controlling the "electronic shutter" of the CCD chip; higher gain in the analog amplifiers preceding digitization; or a larger mechanical iris opening or other external gating means.

These two image inputs are usually generated by a single CCD chip, but may also be generated simultaneously by two separate, boresighted CCD chips, as disclosed in the aforementioned earlier applications. For the more common case in which the two inputs are generated by a single CCD chip, they may be generated either sequentially (as in the case of the first method above — integration time control) or concurrently (by using two input channels with different gain levels). When a sequential method is used, field memories are required at the input to apparatus 10 (in blocks 20 and 22) to synchronize the data coming from the two sequential fields or frames. These memories are not needed in concurrent modes, except for purposes of

"freezing" the image for electronic, digital storage. Switching logic incorporated in blocks 20 and 22 controls the data flow into and out of these field memories, depending on which mode (sequential or concurrent) is used. Of course, this implementation could be expanded to more than two exposure levels. Blocks 24 and 26 may typically be provided on separate processing chips or incorporated together in a single chip. The processing for each exposure is divided into two paths:

1. Color path processing — handles color information for each pixel (see color path block 28 in Figure 3 and, in more detail, in Figure 4); and
2. Intensity (Y) path processing — handles intensity information for each pixel (see Y path block 30 in Figure 3 and, in more detail, in Figure 5).

Additionally, as shown in more detail in Figure 3, long/short exposure processing blocks 24, 26 include mosaic white balance block 32.

Mosaic white balance block 32 receives the following field of information from long/short exposure field blocks 20, 22:

$$
\begin{array}{llllllc}
\alpha & \gamma & \alpha & \gamma & \alpha & \gamma & \ldots. \\
\beta & \delta & \beta & \delta & \beta & \delta & \ldots. \\
\alpha & \gamma & \alpha & \gamma & \alpha & \gamma & \ldots. \\
\beta & \delta & \beta & \delta & \beta & \delta & \ldots. \\
\alpha & \gamma & \alpha & \gamma & \alpha & \gamma & \ldots. \\
\beta & \delta & \beta & \delta & \beta & \delta & \ldots. \\
. & . & . & & & & \\
. & . & . & & & & \\
. & . & . & & & &
\end{array}
$$

That is, the information from CCD 14 with the mosaic data order intact is received.

After processing, the mosaic white balance block 32 outputs color-corrected data values:

$$
\begin{array}{ccccccc}
\alpha_{wb} & \gamma_{wb} & \alpha_{wb} & \gamma_{wb} & \alpha_{wb} & \gamma_{wb} & \cdots \\
\beta_{wb} & \delta_{wb} & \beta_{wb} & \delta_{wb} & \beta_{wb} & \delta_{wb} & \cdots \\
\alpha_{wb} & \gamma_{wb} & \alpha_{wb} & \gamma_{wb} & \alpha_{wb} & \gamma_{wb} & \cdots \\
\beta_{wb} & \delta_{wb} & \beta_{wb} & \delta_{wb} & \beta_{wb} & \delta_{wb} & \cdots \\
\alpha_{wb} & \gamma_{wb} & \alpha_{wb} & \gamma_{wb} & \alpha_{wb} & \gamma_{wb} & \cdots \\
\beta_{wb} & \delta_{wb} & \beta_{wb} & \delta_{wb} & \beta_{wb} & \delta_{wb} & \cdots \\
\cdot & \cdot & \cdot & & & & \\
\cdot & \cdot & \cdot & & & & \\
\cdot & \cdot & \cdot & & & &
\end{array}
$$

Mosaic white balance block 32 contains mosaic color balance functions. These functions may typically be implemented as eight mosaic white balance LUTs (look-up tables). That is, for each exposure there is a set of four LUTs, one for each mosaic data type: α, β, γ, and δ. Independent calculation of white balance correction factors is performed for each exposure. This enables white balancing scenes where the observable parts of the two exposures are at different color temperatures. The LUTs may contain multiplicative correction factors which are evaluated as follows:

From the definitions of α, β, γ, δ and Y it follows, that for a white image (where by definition R=G=B), the following relations should hold:

$$\alpha_{wb} = \frac{6}{7} * Y$$

$$\beta_{wb} = \frac{8}{7} * Y$$

$$\gamma_{wb} = \frac{8}{7} * Y$$

$$\delta_{wb} = \frac{6}{7} * Y$$

Based on these relations correction factors can be calculated by enforcing these relations on the average of a white image:

$$C_\alpha = \frac{\frac{6}{7} * \overline{Y}}{\overline{\alpha}}$$

$$C_\beta = \frac{\frac{8}{7} * \overline{Y}}{\overline{\beta}}$$

$$C_\gamma = \frac{\frac{8}{7} * \overline{Y}}{\overline{\gamma}}$$

$$C_\delta = \frac{\frac{6}{7} * \overline{Y}}{\overline{\delta}}$$

where $\overline{Y}$ denotes a selective average over Y in the given white image and $\overline{\alpha}$, $\overline{\beta}$, $\overline{\gamma}$ and $\overline{\delta}$ are the respective average values of α, β, γ and δ. Saturated or cutoff pixels are excluded from this average. Since by definition,

$$\overline{Y} = \frac{\overline{\alpha} + \overline{\gamma}}{2} = \frac{\overline{\beta} + \overline{\delta}}{2}$$

the equations for the correction factors are:

$$C_\alpha = \frac{3}{7} * \left(1 + \frac{\overline{\gamma}}{\overline{\alpha}} \right)$$

$$C_\beta = \frac{4}{7} * \left(1 + \frac{\overline{\delta}}{\overline{\beta}} \right)$$

$$C_\gamma = \frac{4}{7} * \left(1 + \frac{\overline{\alpha}}{\overline{\gamma}} \right)$$

$$C_\delta = \frac{3}{7} * \left(1 + \frac{\overline{\beta}}{\overline{\delta}} \right)$$

The LUT values are calculated by simple multiplication of each mosaic data type by its respective correction factor:

$$\alpha_{wb} = \alpha * C_\alpha$$
$$\beta_{wb} = \beta * C_\beta$$
$$\gamma_{wb} = \gamma * C_\gamma$$
$$\delta_{wb} = \delta * C_\delta$$

In an alternative embodiment, these LUTs are replaced by digital multipliers. Furthermore, the LUTs may also be loaded with correction functions other than simple linear multiplicative factors. Alternatively, the mosaic balance correction factors can be computed based on four average signals, namely, α, β, γ and δ, instead of merely two of them as above. This alternative yields improved uniformity of color balance under difficult conditions. Alternatively, the white balance function may be done on the RGB color components in the color conversion block 78 (described below).

Referring now to Figure 4, color path block 28 is shown in more detail. As previously stated, the input to color path block 28 is the image data α_{wb}, β_{wb}, γ_{wb}, δ_{wb} after processing by mosaic white balance block 32.

The initial processing of color path block 28 is performed by color difference evaluation block 34 which receives data α_{wb}, β_{wb}, γ_{wb}, δ_{wb} from mosaic white balance block 32 and calculates color difference components dr, db for each pixel in the array:

$$\begin{array}{l} dr\ dr\ dr\ \ldots\ldots = (\gamma-\alpha)\ (\gamma-\alpha)\ (\gamma-\alpha)\ \ldots\ldots \\ db\ db\ db\ \ldots\ldots = (\delta-\beta)\ (\delta-\beta)\ (\delta-\beta)\ \ldots\ldots \\ dr\ dr\ dr\ \ldots\ldots = (\gamma-\alpha)\ (\gamma-\alpha)\ (\gamma-\alpha)\ \ldots\ldots \\ db\ db\ db\ \ldots\ldots = (\delta-\beta)\ (\delta-\beta)\ (\delta-\beta)\ \ldots\ldots \end{array}$$

wherein:

dr $\equiv \gamma - \alpha$, the differences between successive readings in even lines.

$db \equiv \delta - \beta$, the differences between successive readings in odd lines.

The correct evaluation of dr and db requires horizontal interpolation as described in the following equations:

For each pixel (i,j) in even lines i:

$$dr(j_{odd}) = \gamma_{wb}(j_{odd}) - \frac{\alpha_{wb}(j_{odd}-1) + \alpha_{wb}(j_{odd}+1)}{2}$$

$$dr(j_{even}) = \frac{\gamma_{wb}(j_{even}-1) + \gamma_{wb}(j_{even}+1)}{2} - \alpha_{wb}(j_{even})$$

where j is the pixel index along the line (here and henceforth).

For each pixel (i,j) in odd lines i:

$$db(j_{odd}) = \delta_{wb}(j_{odd}) - \frac{\beta_{wb}(j_{odd}-1) + \beta_{wb}(j_{odd}+1)}{2}$$

$$db(j_{even}) = \frac{\delta_{wb}(j_{even}-1) + \delta_{wb}(j_{even}+1)}{2} - \beta_{wb}(j_{even})$$

Color difference components dr, db are thereafter received by low-pass color component block 36 which calculates a low-pass color component dr_{lp} or db_{lp} for each pixel:

$$\begin{aligned}
dr_{lp}dr_{lp}dr_{lp} \ldots\ldots &= (\gamma-\alpha)_{lp}\ (\gamma-\alpha)_{lp} \ldots\ldots \\
db_{lp}db_{lp}db_{lp} \ldots\ldots &= (\delta-\beta)_{lp}\ (\delta-\beta)_{lp} \ldots\ldots \\
dr_{lp}dr_{lp}dr_{lp} \ldots\ldots &= (\gamma-\alpha)_{lp}\ (\gamma-\alpha)_{lp} \ldots\ldots \\
db_{lp}db_{lp}db_{lp} \ldots\ldots &= (\delta-\beta)_{lp}\ (\delta-\beta)_{lp} \ldots\ldots
\end{aligned}$$

Block 36 performs horizontal low-pass filtering on dr_{hp} and db_{hp} calculated in block 34. This reduces color artifacts caused by interpolation. In a preferred embodiment, the low-pass filter width is five pixels and its coefficients are ⅛, ¼, ¼, ¼, ⅛. The equations follow:

For pixels (i,j) in even lines i:

$$dr_{lp}(j) = \frac{dr(j-2) + 2*dr(j-1) + 2*dr(j) + 2*dr(j+1) + dr(j+2)}{8}$$

For pixels (i,j) in odd lines i:

$$db_{lp}(j) = \frac{db(j-2) + 2*db(j-1) + 2*db(j) + 2*db(j+1) + db(j+2)}{8}$$

Delay buffer 38 receives the output from low-pass color component block 36 and directs $db_{lp}(i_{even} -1)$, $dr_{lp}(i_{odd} - 1)$, $db_{lp}(i_{even} +1)$ and $dr_{lp}(i_{odd}+1)$ to vertical interpolation block 40 and $dr(i_{even})$ and $db(i_{odd})$ to multiplexer 42.

Vertical interpolation block 40 receives the low-pass color components as described above and generates interpolated low-pass color components dr'_{lp} in the odd numbered lines and db'_{lp} in the even numbered lines:

$$\begin{array}{lllll}
db'_{lp} & db'_{lp} & db'_{lp} & db'_{lp} & \ldots\ldots \\
dr'_{lp} & dr'_{lp} & dr'_{lp} & dr'_{lp} & \ldots\ldots \\
db'_{lp} & db'_{lp} & db'_{lp} & db'_{lp} & \ldots\ldots \\
dr'_{lp} & dr'_{lp} & dr'_{lp} & dr'_{lp} & \ldots\ldots
\end{array}$$

The equations follow:

For even lines i:

$$db'_{lp}(i,j) = \frac{db_{lp}(i-1,j) + db_{lp}(i+1,j)}{2}$$

For odd lines i:

$$dr'_{lp}(i,j) = \frac{dr_{lp}(i-1,j) + dr_{lp}(i+1,j)}{2}$$

The interpolated low-pass color components dr'_{lp}, db'_{lp} are multiplexed with the original low-pass components dr_{lp}, db_{lp} to give the color path output values dr and dp for each pixel. This function is performed by multiplexer 42, which separates the output received from delay buffer block 38 and vertical interpolator block 40 into a first path including $db_{lp}'(i_{even})$ and $db_{lp}(i_{odd})$ and a second path including $dr_{lp}(i_{even})$ and $dr'_{lp}(i_{odd})$.

Referring now to Figure 5, which discloses in more detail the intensity (Y) processing block 30 shown in Figure 3, one sees that the input to intensity (Y) processing block 30 from mosaic white balance block 32 (Figure 3) is received by intensity evaluation block 44 which outputs computed intensity Y for each pixel.

Since only one of the four data types (α, β, γ, δ) is present at any given pixel, the intensity evaluation block 44 calculation is performed as follows (based on the prior definition of Y):

For pixels (i,j) in even lines i:

$$Y(j_{odd}) = \frac{\gamma(j) + \alpha(j-1)}{2}$$

$$Y(j_{even}) = \frac{\alpha(j) + \gamma(j-1)}{2}$$

For pixels (i,j) in odd lines i:

$$Y(j_{odd}) = \frac{\delta(j) + \beta(j-1)}{2}$$

$$Y(j_{even}) = \frac{\beta(j) + \delta(j-1)}{2}$$

The output from intensity evaluation block 44 is received by delay buffer 46, generate output intensity block 48 and limit block 50.

Delay buffer 46 is a delay line of two horizontal lines, required for the 3x3 and 1x3 matrix transformations in Y path block 30. Together with the color path delay

buffer 38 and with Y path delay buffer 54, it may be implemented in a preferred embodiment in mosaic data space, operating on the input α, β, γ, δ data before the intensity (Y) evaluation block 44 and color difference evaluation block 34. It is shown here schematically for clarity.

Vertical low-pass filter 52 receives intensity (Y) signals from the intensity evaluation block 44 as delayed by delay buffer 46. Block 52 generates the vertical low-pass intensity Y_{vlp} defined as:

$$Y_{vlp}(i,j) = \frac{Y(i-1,j) + 2Y(i,j) + Y(i+1,j)}{4}$$

The unfiltered intensity (Y) input will sometimes exhibit horizontal stripes, one pixel high in each field, in areas of transition to saturation. These stripes stem from the different color spectra of the α, β, γ, and δ pixels, as a result of which the $\alpha+\gamma$ value of Y(i(even),j) may, for instance, reach saturation at a lower level of optical intensity than the $\beta+\delta$ value of the vertically adjacent Y(i+1(odd),j). Y_{vlp} averages these values to obtain a function that is smooth over the transition area.

Generate output intensity block 48 receives intensity (Y) information from intensity evaluation block 44 and vertical low-pass intensity (Y_{vlp}) information from vertical low-pass filter 52. The output of block 48 is output intensity (Y_{out}) to point processing LUT block 62 (see Figure 1).

Block 48 replaces the original luminance Y, computed by the intensity evaluation block 44, with Y_{vlp} when Y_{vlp} approaches saturation, in order to prevent the appearance of horizontal stripes as explained above. Block 48 implements the function:

$$Y_{out} = \begin{cases} Y & \text{if } Y_{vlp} < Y_{threshold} \\ Y_{vlp} & \text{if } Y_{vlp} \geq Y_{threshold} \end{cases}$$

The value of $Y_{threshold}$ is typically equal to approximately 220 on an 8-bit scale of 0-255. As values of Y approach saturation, image detail is lost in any event, so that substituting Y_{vlp} in the high range does not adversely affect the perceived resolution. Y_{vlp} is used as the selecting input in order to ensure a smooth transition.

Limit block 50 receives intensity (Y) signals from intensity evaluation block 44 and generates limited luminance Y_{limit}. Limit block 50 cuts off the upper range of intensity (Y) values that are to be input to edge detection block 56, in order to prevent detection of false edges or horizontal stripes that can arise in areas of transition to saturation. Limit block 50 implements the function:

$$Y_{limit} = \min \{Y, Y_{lim}\}$$

the value of Y_{lim} is typically equal to approximately 220.

The output of limit block 50 (i.e., Y_{limit}) is delayed by delay buffer 54 and received by edge detection block 56 which outputs edge information for each pixel.

Edge detector block 56 convolves the Y_{limit} value and its 8 immediate neighbors, with a high-pass or edge detecting kernel.

In one embodiment, the 3x3 Laplacian operator may be used:

$$\frac{1}{8} * \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

Alternatively, to accommodate the geometric characteristics of the CCD raster and to give greater

emphasis to the vertical edges, the following kernel may be used:

$$\frac{1}{8} * \begin{bmatrix} -\frac{1}{2} & -1 & -\frac{1}{2} \\ -2 & 8 & -2 \\ -\frac{1}{2} & -1 & -\frac{1}{2} \end{bmatrix}$$

In an alternative embodiment, the edge detector block 56 could be implemented as separate horizontal and vertical convolution operations (such as a 1 x 3 or 3 x 1 matrix), with additional logic to avoid overemphasis of diagonal edges. This alternative embodiment is less hardware intensive and gives improved picture quality in some circumstances.

Edge suppress block 58 receives the vertical low-pass intensity (Y_{vlp}) signals from vertical low-pass filter 52 and outputs edge suppression function f_{edge} to edge multiplier 60.

The edge suppression function varies between 0 and 1 in the long exposure processing block 24 only. In the short exposure processing block 26, the function is set to 1, i.e., no edge suppression at this point. The function is typically implemented in block 24 in a piecewise linear fashion as follows:

$$f_{edge} = \begin{cases} 1 & \text{if } Y_{vlp} < \text{LOWSAT} \\ 1 - \dfrac{Y_{vlp} - \text{LOWSAT}}{\text{DEEPSAT} - \text{LOWSAT}} & \text{if LOWSAT} \le Y_{vlp} < \text{DEEPSAT} \\ 0 & \text{if DEEPSAT} \le Y_{vlp} \end{cases}$$

Typically LOWSAT is set to approximately 190 and DEEPSAT to approximately 220.

Edge multiplier 60 receives input from blocks 56, 58 and generates suppressed edge ed_{supp} to intensity (Y) result calculation.

Edge multiplier 60 multiplies the edge output of the edge detector block 56 by the edge suppression function f_{edge}

from block 58 to generate an output value ed_{supp} to joint operations block 64 (see Figure 1). The purpose of this multiplication is to suppress distorted large edges that may appear in the long exposure at intensity (Y) values near saturation, at the same time as they appear in the short exposure at lower values of intensity (Y). The double appearance of such edges was found empirically to cause the resulting displayed edges to be overemphasized and sometimes smeared on account of blooming in the long exposure. The long exposure edge is suppressed so that only the short exposure edge will pass through to the output image. The edge suppress function may also be used to reduce the amplitude of edges from the long exposure which may be otherwise exaggerated due to the higher gain of the long exposure relative to the short exposure.

Additionally, as shown in phantom in Figure 5, an optional multiplier or LUT (block 57) may be added to multiply the output of block 56 times the ratio of exposure times (duration of long exposure/duration of short exposure) or the corresponding gain ratio, or some function of the exposure and/or gain ratio. This reflects the ratio of scales of these two values.

In the above manner, Y path block 30 outputs processed luminance Y_{out}, edge, and $edge_{supp}$ to point processing block 62 and joint operations block 64.

Referring now to Figure 6, one sees that point processing block 62 includes four point processing functions, all of which receive output intensity (Y_{out}) values from the long and short exposure processing blocks 24, 26 (see Figure 1). These functions may typically be implemented as LUTs in RAM or ROM memory. Point processing block 62 generates arbitrary function values for input to the joint operations block 64 (Figure 1).

The four tables of block 62 are:

1. The intensity (DC result) block 66 which generates a LUT value of intensity (Y_{lut}) for the joint operations block 64.

Block 66 controls the amount of point ("DC") luminance that is summed with the edge information in generating the output luminance, Y_{result}. In its most general formulation,

$$Y_{lut} = f(Y_{out}^{(short)}, Y_{out}^{(long)})$$

where f is an arbitrary function. It has been found that a quasilogarithmic or fractional power dependence of Y_{lut} on the inputs gives the best output image appearance, and the general function above can generally be reduced to a more compact LUT or piecewise linear implementation.

One simple possible computation of Y_{lut} is as follows:

a) Y_{short} is multiplied by the exposure ratio, so that it is on the same scale as Y_{long}. That is, if a certain pixel x is acquired within the active (linear) sensitivity region of both the short and long exposures, then $Y_{long}(x) = R*Y_{short}(x)$, where R is the exposure ratio, R=long exposure time/short exposure time (or any other ratio representing the two sensitivities).

b) Subsequently, Y_{long} and $R*Y_{short}$ are linearly combined, so that the sum of their relative weights is always 1. That is, $Y_{wdr}=a*Y_{long} + b*R*Y_{short}$, $1\geq a\geq 0$, $1\geq b\geq 0$, and a+b=1 (the wdr index stands for 'wide dynamic range'). The common practice is to set a=1 in the region where the short exposure is cut-off (too dark), b=1 in the region where the long exposure is saturated (too

bright), and a>0, b>0 in the region where both exposures carry meaningful information. However, this does not cover all cases, e.g. when neither exposure carries any information (long is saturated and short is cut-off, or both saturated, or both cut-off).

c) Finally, the dynamic range of Y_{wdr} is reduced (yielding Y_{lut}) by either a logarithmic function, or by multiplying it by a small fraction, or by using any empirically found mapping which resembles the log function or a similar contraction, e.g., the square root.

Other possible values for Y_{lut} comprise empirical modifications of the function described above.

2. & 3. Color weight normalize blocks 68, 70 for long and short exposures, respectively, which generate normalizing color weights w_l/Y_l and w_s/Y_s. Blocks 68 and 70 control the proportions of mixing the color values, dr and db, from the long and short exposures, respectively, that will be used to generate the output color values, dr_{result} and db_{result}. Generally, w_l and w_s are chosen so as to give predominant weight at each pixel to the color values taken from the exposure in which the intensity (Y) luminance values are in the linear portion of the range, and to give a smooth transition over luminance gradient regions of the image. For the most part, w_l and w_s are determined on the basis of Y_{out}(long) alone, except for cases where the long exposure is near saturation while the short is near cutoff, so that neither gives a linear reading.

The weighting values are complementary, i.e., $w_l = 1 - w_s$, and w_l, $w_s \geq 0$. The outputs of blocks 68 and 70 are normalized by division by

the corresponding values of Y_{out} for the long and short exposures. Preferably, a floating point representation for the output values of blocks 68, 70 is used so as to maintain sufficient accuracy to prevent noticeable quantization in the output image.

Alternatively, instead of weighted addition of the normalized color from the two exposures, simple selection of the normalized color from one exposure or the other, with an ordered dither (alternation) of the color selection in areas of transition may be used. In this case, when w_l = 1, the color is selected from the long exposure; when w_s = 1, it is selected from the long exposure, and when neither w factor is 1, color values are taken alternately from long and short, according to a pseudo-random probability distribution in which the long and short color value probabilities are equal to the w_l and w_s values. A normalized color value that is an average of the long and short values may also be mixed into the dither, in order to give a smoother color transition.

4. Saturation color suppression factor block 72 generates the color suppression factor Wht that reduces chroma saturation (adds white to the image) in areas of luminance saturation of the input image. An additional edge color suppression factor, Z_{cd}, is computed in the joint operations block (as will be described hereinafter). The minimum of Wht and Z_{cd}, both of which vary from 1 to 0, multiplies the chroma components at the output stage of color conversion. Thus, as Wht approaches zero, so does the color saturation of the output image.

The purpose of the saturation color suppression function is to reduce the appearance of color artifacts that arise due to CCD saturation. The linear relationships between the α, β, γ, and δ CCD outputs and the true RGB colors break down as the CCD 14 approaches saturation. As non-linear deviations cannot be readily corrected, suspected distorted colors are "whitewashed". Similar techniques are used in the analog domain in conventional CCD cameras. As shown in Figure 6:

$$Wht = w_l + w_s * z_s$$

w_l and w_s are identical to the above color weighting values. The variable Z_s is a function of Y_{out}(short), varying between 0 and 1, as shown schematically in the lower right corner of Figure 6. It tends to zero in areas where the short exposure luminance approaches either saturation or cutoff. This function will give Wht = 0 at the saturation end (where generally $w_s = 1$ while $w_l = 0$). At the cutoff end, normally $w_l \approx 1$ as long as there is adequate overlap between the long and short exposures, so that in this range the function will usually give Wht $\approx$ 1.

In normal mode, in which only one input channel is operative (see explanation below), Wht = 1 from Y=0 up to the low saturation threshold (typically 190). From this threshold up to the deep saturation limit of Y (typically 220), Wht drops linearly to its saturation value of 0. In replay mode (see below), there is no saturation color suppression.

Figure 7 discloses the joint operations block 64 (also see Figure 1).

Joint operations block 64 combines the chrominance and luminance data from the long and short exposure processing blocks 24, 26, together with data from point processing block 62, to generate a combined Y/dr/db result. Block 64 then converts this result to output in standard RGB or Y/Cr/Cb (luminance, chrominance (red) and chrominance (blue)) color space. A color suppression factor Z is computed and applied to the chrominance outputs in order to reduce color artifacts (by reducing chroma saturation) around edges and areas of luminance signal saturation.

Joint operations block 64 includes:

1. The dr, db, Y block 74 (recalling that dr and db are the differences between successive readings in even and odd lines, respectively) which receives dr, db values from the color path outputs of long and short exposure processing blocks 24, 26 respectively; ed_{supp} from the intensity (Y) path output of long exposure processing block 24 and edge data from the intensity (Y) path output of short exposure processing block 26; and Y_{LUT}, w_l/Y_l and w_s/Y_s from table processing (LUT) block 62. Block 74 generates combined intensity Y/dr/db results to color conversion block 78 (to be discussed). Block 74 will be discussed in greater detail hereinafter.
2. The color suppression factor block 76 which receives ed_{long} and ed_{short} from edge detector block 56 and saturation color suppression factor (Wht) from point processing block 62 and generates chroma suppression factor Z for color conversion block 78. Block 76 will be discussed in greater detail hereinafter.

3. The color conversion block 78 which receives Y_{result}, dr_{result}, db_{result} from block 74 and Z, the color suppression factor from block 76 and generates R_{out}, G_{out}, and B_{out} and Cr and Cb. Block 78 will be discussed in greater detail hereinafter.

The dr, db, Y block 74 is shown in further detail in Figure 8.

Block 74 includes an intensity (Y) calculation which is performed by adders 79, 80 and edge limiting block 81. Adder 79 receives ed_{supp} (long) data from long exposure processing block 24, and ed_{short} from short exposure processing block 26. These two inputs are added to give $edge_{result}$, which is then input to the edge limiting block 81. Edge limiting is implemented as a piecewise linear function with 6 inflection points ($A_1 \ldots A_6$) and 4 slopes ($S_1 \ldots S_4$), as shown in the upper right inset of Figure 8. Generally the inflection points and slopes are chosen so as to enhance the smaller edges (i.e., S_2 and $S_3 \geq 1$), while large edges (edge > A_5 or < A_2) are suppressed. Since these large edges come through strongly in the Y_{LUT} contribution anyway, the output image has a more pleasing appearance if they are not additionally enhanced. A_3 and A_4 may be set to 0, but it is sometimes desirable to set them to small non-zero values in order to suppress false edges due to noise. The best results appear to be obtained with $|A_1|$ and $|A_6|$ values of 50 to 60. The best values of the slopes $|S_i|$ are typically in the range 0.5 to 2, but the hardware allows a greater range.

The $edge_{limited}$ output is then summed by adder 80 with the Y_{LUT} output of block 62 to obtain the output luminance value Y_{result}. Additionally, as shown in phantom in Figure 10, adder 80 may be removed from its location in Figure 8 and placed

so thac the output of block 81 is not added to Y_{result} until just before being added into block 113_{A-C}, that is, as late as possible.

Block 74 further includes a dr, db calculation which is performed by the remaining sections of block 74. The dr, db calculation receives low-pass color components dr, db from the color paths of long and short exposure processing blocks 24, 26; w_l/Y_l and w_s/Y_s from block 62; and Y_{result} as calculated by adder 80. The dr, db calculation outputs dr_{result} and db_{result}.

The long and short values of dr and db are multiplied by the respective normalized color weights, w_l/Y_l and w_s/Y_s by multipliers 82, 84, 86, 88. These normalized, weighted color values from the two exposures are summed together by adders 90, 92 and then multiplied by Y_{result} by multipliers 94, 96 to give the scaled values:

$$dr_{result} = Y_{result} * \left\{ dr_l \frac{w_l}{Y_l} + dr_s \frac{w_s}{Y_s} \right\}$$

$$db_{result} = Y_{result} * \left\{ db_l \frac{w_l}{Y_l} + db_s \frac{w_s}{Y_s} \right\}$$

Alternatively, dr_{result} and db_{result} may be generated by selection between the long and short normalized dr and db inputs (and possibly their long/short average values).

The color suppression factor block 76 of Figure 7 is shown in more detail in Figure 9.

Maximum value block 100 selects the higher of the two absolute values of ed_{long} and ed_{short} as calculated by absolute value blocks 98, 99. The result of the calculation of block 100, ed_{max}, is input to edge chroma suppression factor block 102 to calculate Z_{ed}. The calculation of Z_{ed} is implemented as a piecewise linear function, shown in the upper right corner of Figure 9. As can be seen in Figure 9, Z_{ed} receives a value between Th and 1, given by:

$$Z_{cd} = \begin{cases} 1 & \text{if } ed_{max} < E1 \\ Th + \dfrac{E2 - ed_{max}}{E2 - E1}(1 - Th) & \text{if } E1 \leq ed_{max} < E2 \\ Th & \text{if } E2 \leq ed_{max} \end{cases}$$

Typically, E1=10 and E2=27 have been found to give good results. The minimum value of Z_{cd}, Th, is ordinarily set to zero, to give complete chroma suppression at very strong edges. Th $\neq$ 0 is used only in replay of images stored in mosaic format (see generate mosaic block 120 described hereinafter), in which case Z_{cd} serves to suppress color anomalies resulting from the reinterpolation of the pixel values.

Thereafter, as shown in Figure 9, minimum value block 104 selects the minimum of the two color suppression factors, Z_{cd} and Wht, thereby determining the edge criterion or saturation criterion that should be used to provide the required degree of chroma suppression at the given pixel.

Referring now to Figure 10, which discloses in detail color conversion block 78 of Figure 7, one sees that color conversion block 78 receives Y_{result}, dr_{result}, and db_{result} from block 74 and Z from block 76 and generates outputs in both the RGB and Y/Cr/Cb formulations.

In other words, block 78 takes the interim dynamic range enhancement results Y/dr/db, and converts them into conventional color components for system output.

Block 78 includes horizontal low-pass filter 106 which receives Y_{result} and calculates Y_{result} (lp) for the color matrix block 108.

Horizontal low-pass filter 106 is identical to the low-pass color component block 36 in the color path block 28 (see Figures 3 and 4). Since the dr and db inputs to the color matrix 108 have already been low-pass filtered by this low-pass filter operator, it is necessary to filter

the intensity (Y) value as well in order to prevent color artifacts.

Color matrix block 108 receives Y_{result} (lp) from horizontal low-pass filter 106 and dr_{result} and db_{result} from block 74 and generates low-pass RGB color component outputs.

If one recalls the derivation of Y, dr and db from the original α, β, γ and δ values of the mosaic CCD input:

$$Y \equiv \frac{\alpha + \gamma}{2} \equiv \frac{\beta + \delta}{2}$$

$$dr \equiv \gamma - \alpha$$

$$db \equiv \delta - \beta$$

together with the RGB equivalencies of α, β, γ and δ, one obtains the following relationships between RGB and the Y/dr/db values:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = 3.5 * \begin{bmatrix} 0.2 & 0.4 & 0.1 \\ 0.4 & -0.2 & 0.2 \\ 0.2 & -0.1 & -0.4 \end{bmatrix} \begin{bmatrix} Y \\ dr \\ db \end{bmatrix}$$

The factor of 3.5 is required for normalization of the relation Y = R + 1.5G + B. Due to hardware implementation considerations, the color conversion matrix is calculated as follows:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = 0.7 * \begin{bmatrix} 1.0 & 2.0 & 0.5 \\ 2.0 & -1.0 & 1.0 \\ 1.0 & -0.5 & -2.0 \end{bmatrix} \begin{bmatrix} Y \\ dr \\ db \end{bmatrix}$$

In this way the matrix multiplication is performed by a series of shift/add operations. The multiplicative factor 0.7 is combined (by multiplication) with externally programmed RGB white balance correction factors as is described hereinafter.

RGB white balance multipliers 109_A, 109_B, 109_C receive low-pass RGB signals from color matrix block 108 and generate normalized low-pass RGB signals.

Multipliers 109_A, 109_B, 109_C multiply each of the RGB low-pass values by a pre-computed white balance correction factor, adjusted by the normalization factor 0.7 required by the color matrix calculation. Although conventional RGB white balancing uses only two multiplicative factors, correcting R and B while G is held constant, this "short cut" does not preserve constant Y achromatic luminance. This loss of normalization may lead to the appearance of artifacts and incorrect luminance in the output. It is necessary, therefore, to use three multiplicative factors, normalized to preserve constant luminance Y.

The calculation of the correction factors is performed off-line by capturing a white image and selectively computing average values $\overline{R}$, $\overline{G}$, $\overline{B}$, and $\overline{Y}$, excluding pixels near saturation or cutoff. From the definition $Y = R + 1.5G + B$, it follows that for a corrected pixel in the white image, it should be found that:

$$R = G = B = \frac{1}{3.5} Y$$

From this relationship one derives the correction factors to be used in multipliers 109_A, 109_B, 109_C:

$$R \text{ factor} = \frac{1}{3.5} \frac{\overline{Y}}{\overline{R}}$$

$$G \text{ factor} = \frac{1}{3.5} \frac{\overline{Y}}{\overline{G}}$$

$$B \text{ factor} = \frac{1}{3.5} \frac{\overline{Y}}{\overline{B}}$$

Output signal enhancement block 110 (which includes chroma suppression and RGB output functions) receives

corrected low-pass RGB color component signals from color matrix block 108 via multipliers 109_A, 109_B, 109_C; Y_{result} from block 74; Y_{result} (lp) from block 106; and chroma suppression factor Z from block 76.

As noted above, the RGB values output from color matrix block 108 are low-pass values. High-frequency image information is "re-injected" into RGB according to the following equation (given here only for the R component, since the treatment of G and B is identical):

$$R_{hp} = R_{lp} + K*Y_{result} - K*Y_{result}^{(lp)}$$

K is an arbitrary constant between 0 and 1, chosen according to the degree of high-frequency enhancement required. Values in the range $0.4 \leq K \leq 0.8$ are typically used.

The addition and subtraction of Y_{result} values to the RGB components can alter the original values of R/G and B/G, with the result that the correct hue of the image is not preserved. Therefore, in an alternative embodiment, R, G and B are multiplied by a high-pass enhancement function.

Since the RGB color component values contain both luminance and chrominance information, the chroma suppression factor, Z, is best applied to chrominance-only components, by adders 113_A, 113_B, 113_C:

$$Cr = R - Y_{result}$$

$$Cg = G - Y_{result}$$

$$Cb = B - Y_{result}$$

Combining these equations with the previous ones for "high frequency re-injection", one obtains the following formula, which is implemented as shown in Figure 10 (including arithmetic element blocks 114, 115, 116) to obtain Cr from R_{lp}:

$$Cr = R_{lp} + K*(Y_{result} - Y_{result}^{(lp)}) - Y_{result}$$

and likewise for Cg and Cb. These Cr/Cg/Cb values are multiplied by Z by multipliers 112_A, 112_B, 112_C. At this point, Y/Cr/Cb output is available directly (using $Y = Y_{result}$), though it is preferable to add a bias of +128 to the signed digital outputs Cr and Cb in order to convert them to positive values for D/A conversion. In the alternative, Y_{result} can be added back into the chroma-suppressed Cr/Cg/Cb values (by adders 113_A-113_C) to obtain the final $R_{out}/G_{out}/B_{out}$.

Referring now to Figure 11, which discloses generate mosaic block 120 of Figure 1 in more detail, one sees that the input of generate mosaic block 120 is $R_{out}/G_{out}/B_{out}$ from color conversion block 78 of joint operations block 64. The output of block 120 is the equivalent α, β, γ, δ values in the format:

$$\begin{matrix} \alpha_{eq} & \gamma_{eq} & \alpha_{eq} & \gamma_{eq} & \cdots \\ \beta_{eq} & \delta_{eq} & \beta_{eq} & \delta_{eq} & \cdots \\ \alpha_{eq} & \gamma_{eq} & \alpha_{eq} & \gamma_{eq} & \cdots \\ \beta_{eq} & \delta_{eq} & \beta_{eq} & \delta_{eq} & \cdots \end{matrix}$$

In order to reduce memory requirements for image storage and to allow stored images to be replayed through the apparatus 10 for display, the final RGB values from the processed image are used to generate equivalent, simulated mosaic values of α, β, γ, and δ. In this way, only eight bits per pixel of information must be stored, rather than the 24 bits of full output information. These mosaic values can later be replayed to regenerate the stored image.

The simulated mosaic values are generated by the following matrix in matrix block 122, based on the color equivalencies given hereinabove.

$$\begin{pmatrix} \alpha_{eq} \\ \beta_{eq} \\ \gamma_{eq} \\ \delta_{eq} \end{pmatrix} = \tfrac{1}{4} * \begin{bmatrix} 0 & 2 & 1 \\ 1 & 1 & 2 \\ 2 & 1 & 1 \\ 1 & 2 & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The factor of ¼ that multiplies the matrix is used for reasons of hardware convenience — in order to ensure that α, β, γ, and δ do not overflow the range 0-255 of 8 bits. To maintain the normalization relations given hereinabove, the factor should actually be 1/3.5. Therefore, in replay mode, mosaic white balance block 32 is used to multiply the α, β, γ, and δ values back by 4/3.5 (=8/7) before reprocessing. Finally, multiplexer 124 selects which one of the four mosaic values to output for each pixel according to the table:

$\text{Pixel}_{i,j}$	j even	j odd
i even	α	γ
i odd	β	δ

Apparatus 10 has three modes of operation: normal, adaptive sensitivity (AS), and replay.

1. Normal mode emulates the performance of a mosaic color CCD camera without adaptive sensitivity. In this mode only the long exposure portion of the pipeline operates. The processing functions are limited to decoding the mosaic input into conventional color components: Y/Cr/Cb or RGB, while additionally performing filtering operations for anti-aliasing, detail (edge) enhancement and chroma suppression where required.

2. Adaptive sensitivity mode uses all the resources of the processing pipeline to generate wide dynamic range images as described hereinabove.

3. Replay mode is required for displaying images that have been stored in RAM or disk. Apparatus 10 stores these images in a regenerated mosaic format in order to save on storage memory requirements. Replay mode is similar to normal mode, except that most of the enhancement operations are not performed: since the stored data have already been filtered once, it is for the most part not desirable to filter them again.

The preceding specific embodiments are illustrative of the practice of the invention. It is to be understood, however, that other expedients known to those skilled in the art or disclosed herein, may be employed without departing from the spirit of the invention or the scope of the appended claims.

CLAIMS

What is Claimed is:

1. A color wide dynamic range video imaging apparatus comprising:

sensor means for providing a plurality of color video images of a scene at different exposure levels;

means for dividing each color video image into components; and

means for processing said components of each of said plurality of video images to produce a combined color video image including image information from said components of each of said plurality of color video images by applying neighborhood transforms to at least one of said components of each of said plurality of video images,

wherein said means for processing includes means for calculating point intensity data for said each of said plurality of said video images.

2. The color wide dynamic range video imaging apparatus of Claim 1, wherein said means for processing includes means for calculating color weighting factors.

3. The color wide dynamic range video imaging apparatus of Claim 2, wherein said means for processing includes means for calculating saturation color suppression factors.

4. The color wide dynamic range video imaging apparatus of Claim 1, wherein said means for dividing each color video image into components includes a filter means in front of said sensor means and said filter means includes filter elements of a plurality of colors, said plurality of colors corresponding to said components.

5. The color wide dynamic range video imaging apparatus of Claim 4, wherein said sensor means includes a plurality of pixel sensing elements and

wherein said filter elements are arranged in a regular repeating pattern with each filter element in front of a single pixel element of said sensing means.

6. The color wide dynamic range video imaging apparatus of Claim 5, wherein said processing means includes means for evaluating an intensity of each color component;

means for evaluating color suppression factors for each pixel; and

means for converting said components into RGB color space.

7. The color wide dynamic range video imaging apparatus of Claim 6, wherein said means for evaluating an intensity of each color component communicates with a means for substituting luminance values when luminance otherwise approaches saturation.

8. The color wide dynamic range video imaging apparatus of Claim 6, wherein said means for evaluating an intensity of each color component communicates with a means for limiting luminance values.

9. The color wide dynamic range video imaging apparatus of Claim 5, wherein said processing means includes white balancing means which calculates correction factors for said components based upon the intensity of said color video images.

10. The color wide dynamic range video imaging apparatus of Claim 9, wherein white balancing means

calculates an average intensity of said color video images excluding saturated pixels and cut-off pixels.

11. The color wide dynamic range video imaging apparatus of Claim 9, including vertical low-pass filter means receiving intensity and false edge suppression means, wherein said false edge suppression means receives intensity data from said vertical low-pass filter means and calculates false edge suppression factors which are reduced when said intensity data exceeds a pre-selected saturation value.

12. The color wide dynamic range video imaging apparatus of Claim 11, wherein said false edge suppression means calculates said false edge suppression factors for an image of a longest of said different exposure levels.

13. The color wide dynamic range video imaging apparatus of Claim 12, further including edge detection means and wherein an output of said edge detection means is multiplied times said false edge suppression factors.

14. The color wide dynamic range video imaging apparatus of Claim 5, wherein color components are calculated by multiplying an intensity times a sum of products of prior color components and output of said means for calculating said color weighting factors.

15. The color wide dynamic range video imaging apparatus of Claim 6, including means for calculating white balance correction factors for said components converted into RGB color space, wherein said white balance correction factors for a given respective RGB component are calculated by dividing average overall luminance by a multiple of an average value of said respective given RGB component.

16. The color wide dynamic range video imaging apparatus of Claim 15, wherein said average value of said respective given RGB component is calculated excluding pixels which are substantially near saturation or substantially near cut-off.

17. The color wide dynamic range video imaging apparatus of Claim 6, including means for converting said RGB color space components into mosaic color components corresponding to colors of said filter elements of said filter means.

18. The color wide dynamic range video imaging apparatus of Claim 1, wherein said means for processing is implemented on a single chip.

19. An imaging apparatus comprising:

sensor means for providing a plurality of color video images of a scene at different exposure levels;

means for dividing each color video image into components; and

means for processing said components of each of said plurality of video images to produce a combined color video image including image information from said components of each of said plurality of color video images by applying neighborhood transforms to at least one of said components of each of said plurality of video images,

wherein said means for processing includes means for calculating point intensity data for said each of said plurality of said video images, and

wherein said processing means includes white balancing means which calculates correction factors for said components based upon the intensity of said color video images.

20. A color wide dynamic range video processing chip comprising:

means for processing components of each of a plurality of video images of a scene at different exposure levels to produce a combined color video image including image information from said components of each of said plurality of color video images by applying neighborhood transforms to at least one of said components of each of said plurality of video images,

wherein said means for processing includes means for calculating point intensity data for said each of said plurality of said video images.

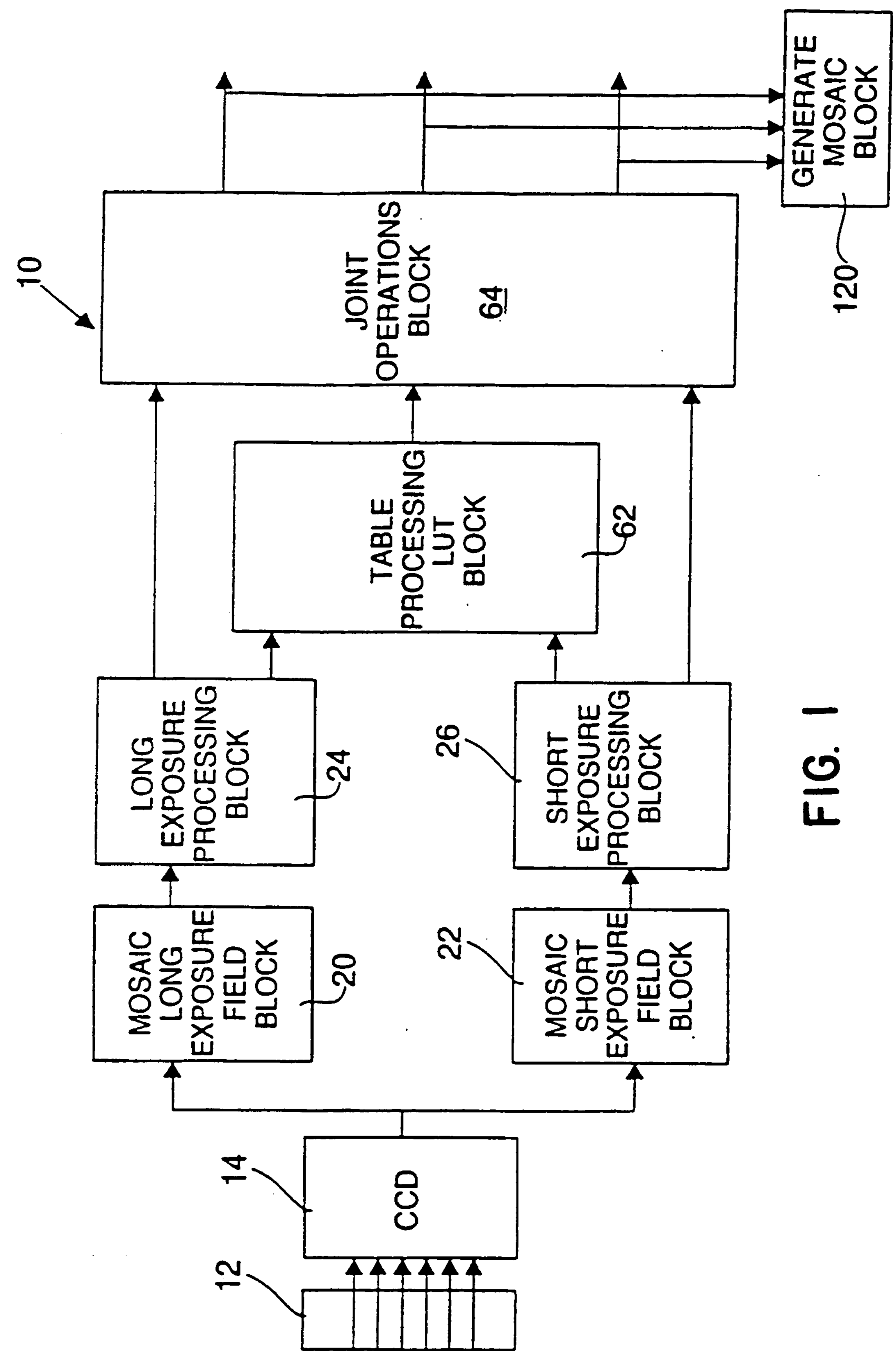

10
JOINT OPERATIONS BLOCK
64
GENERATE MOSAIC BLOCK
120
TABLE PROCESSING LUT BLOCK
62
LONG EXPOSURE PROCESSING BLOCK
24
SHORT EXPOSURE PROCESSING BLOCK
26
MOSAIC LONG EXPOSURE FIELD BLOCK
20
MOSAIC SHORT EXPOSURE FIELD BLOCK
22
CCD
14
12

FIG. 1

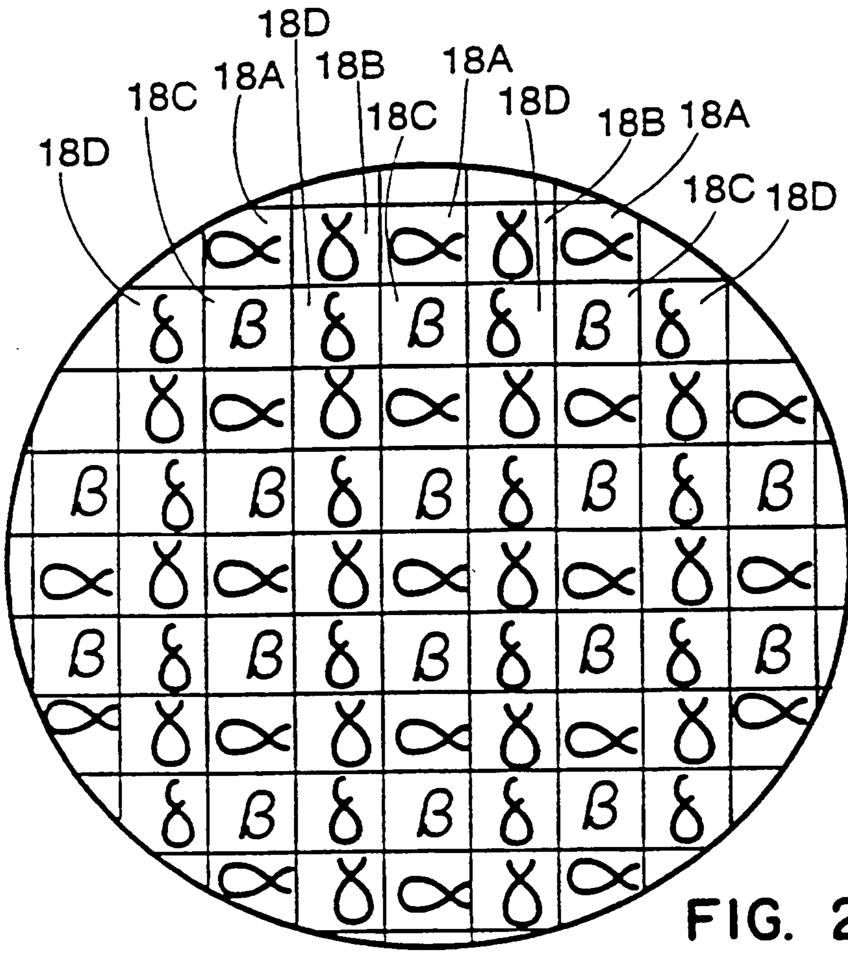

18D
18C
18A
18D
18B
18C
18A
18D
18B
18A
18C
18D
α
β
γ
δ

FIG. 2

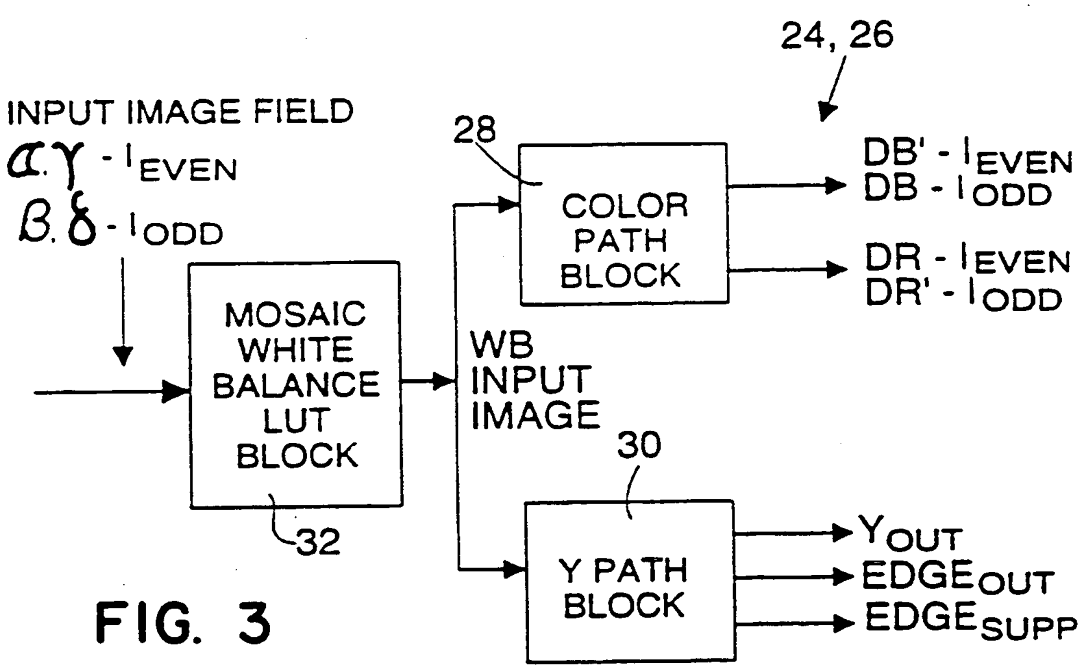

INPUT IMAGE FIELD
$\alpha.\gamma$ - I_{EVEN}
$\beta.\delta$ - I_{ODD}
MOSAIC WHITE BALANCE LUT BLOCK
32
WB INPUT IMAGE
28
COLOR PATH BLOCK
24, 26
DB' - I_{EVEN}
DB - I_{ODD}
DR - I_{EVEN}
DR' - I_{ODD}
30
Y PATH BLOCK
Y_{OUT}
$EDGE_{OUT}$
$EDGE_{SUPP}$

FIG. 3

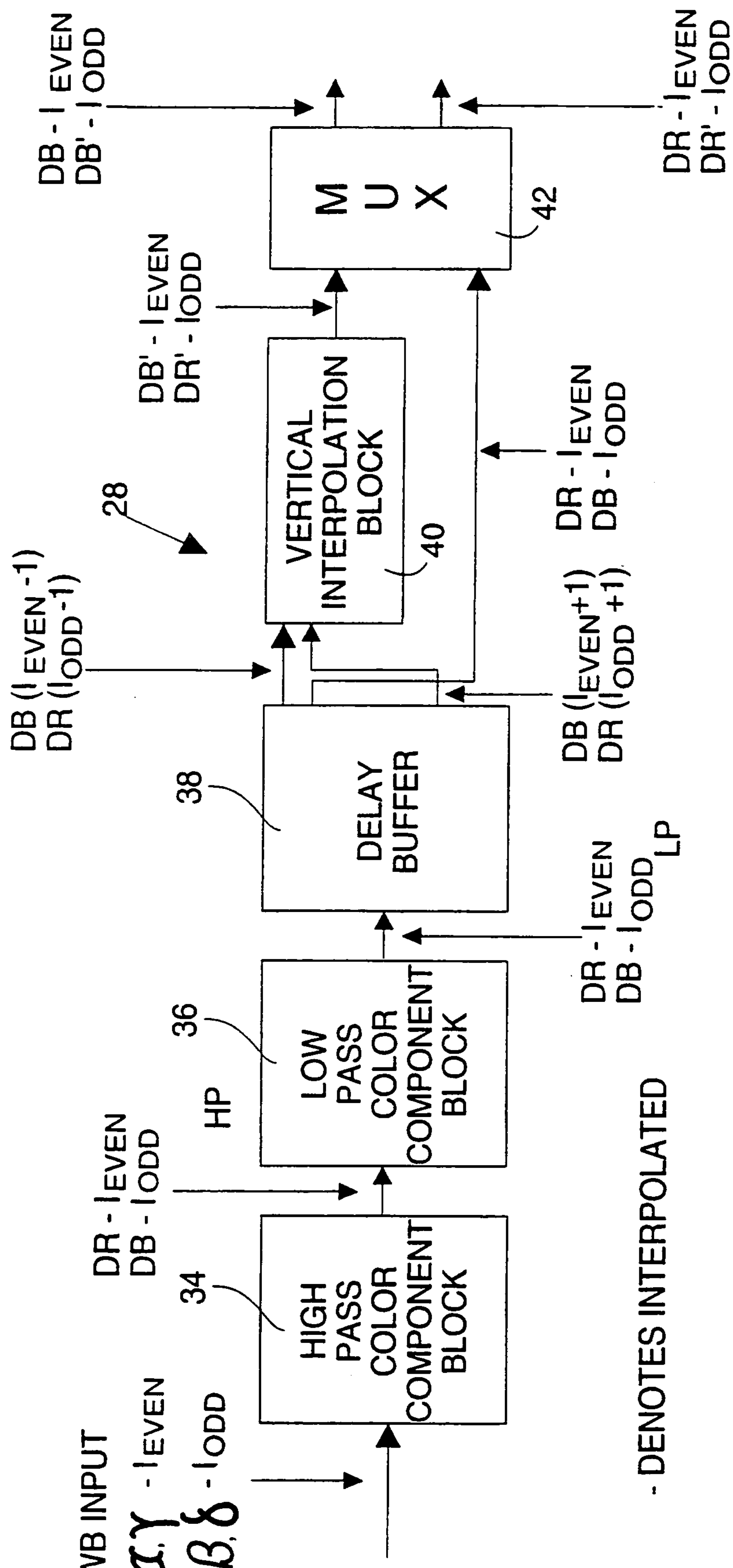

WB INPUT
αγ - IEVEN
βδ - IODD
HIGH PASS COLOR COMPONENT BLOCK
34
DR - IEVEN
DB - IODD
HP
LOW PASS COLOR COMPONENT BLOCK
36
DR - IEVEN
DB - IODD LP
DELAY BUFFER
38
DB (IEVEN -1)
DR (IODD -1)
DB (IEVEN +1)
DR (IODD +1)
VERTICAL INTERPOLATION BLOCK
40
28
DR - IEVEN
DB - IODD
DB' - IEVEN
DR' - IODD
MUX
42
DB - IEVEN
DB' - IODD
DR - IEVEN
DR' - IODD
' - DENOTES INTERPOLATED

FIG. 4

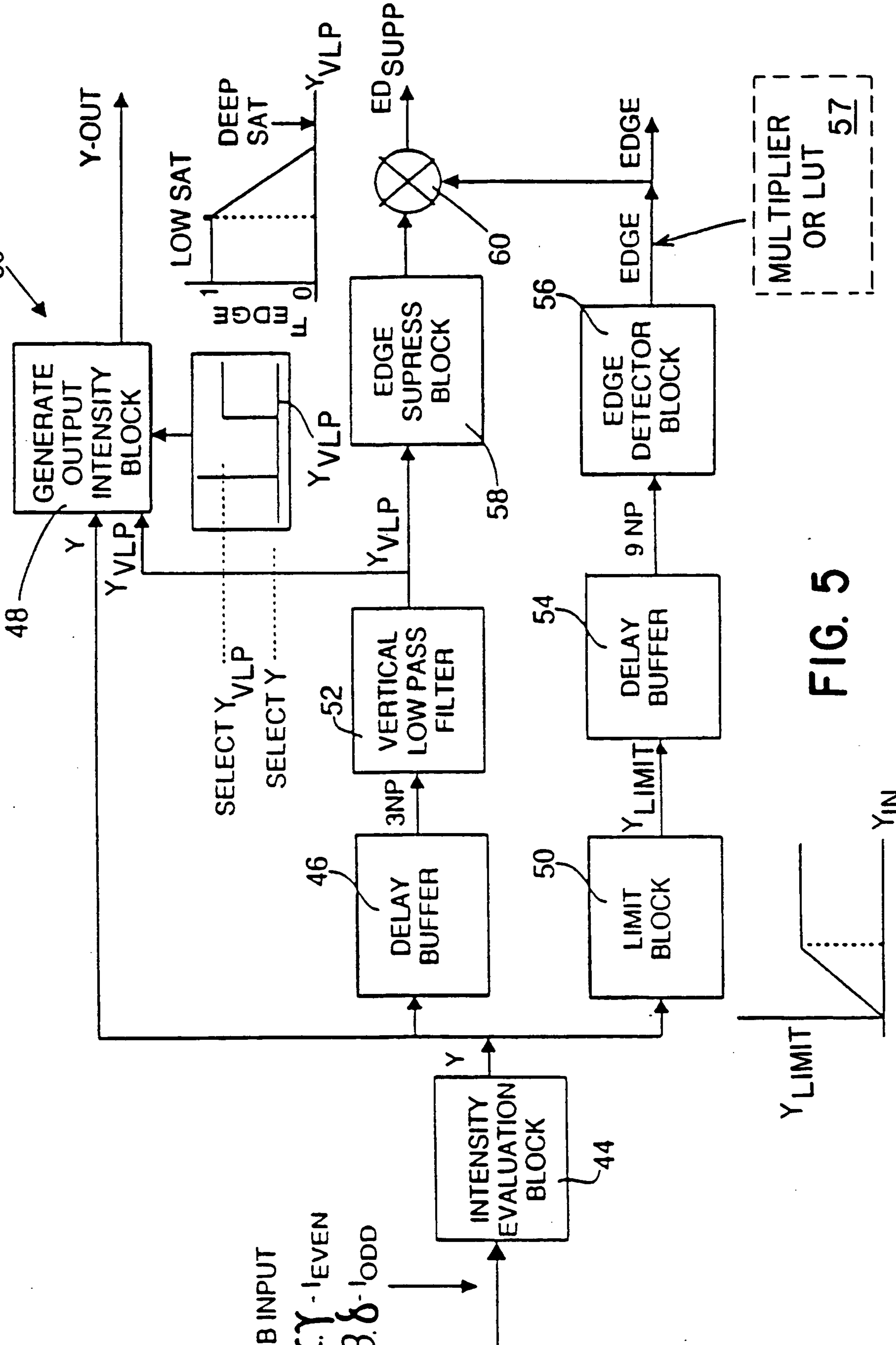

30
Y-OUT
GENERATE OUTPUT INTENSITY BLOCK
48
Y
Y_{VLP}
LOW SAT
DEEP SAT
Y_{VLP}
Π_{EDGE}
1
0
ED_{SUPP}
EDGE SUPRESS BLOCK
58
60
EDGE
EDGE
MULTIPLIER OR LUT 57
EDGE DETECTOR BLOCK
56
SELECT Y_{VLP}
SELECT Y
VERTICAL LOW PASS FILTER
52
3NP
DELAY BUFFER
46
DELAY BUFFER
54
9 NP
Y_{LIMIT}
LIMIT BLOCK
50
Y_{LIMIT}
Y_{LIM}
Y_{IN}
Y
INTENSITY EVALUATION BLOCK
44
WB INPUT
$\alpha.\gamma - I_{EVEN}$
$\beta.\delta - I_{ODD}$

FIG. 5

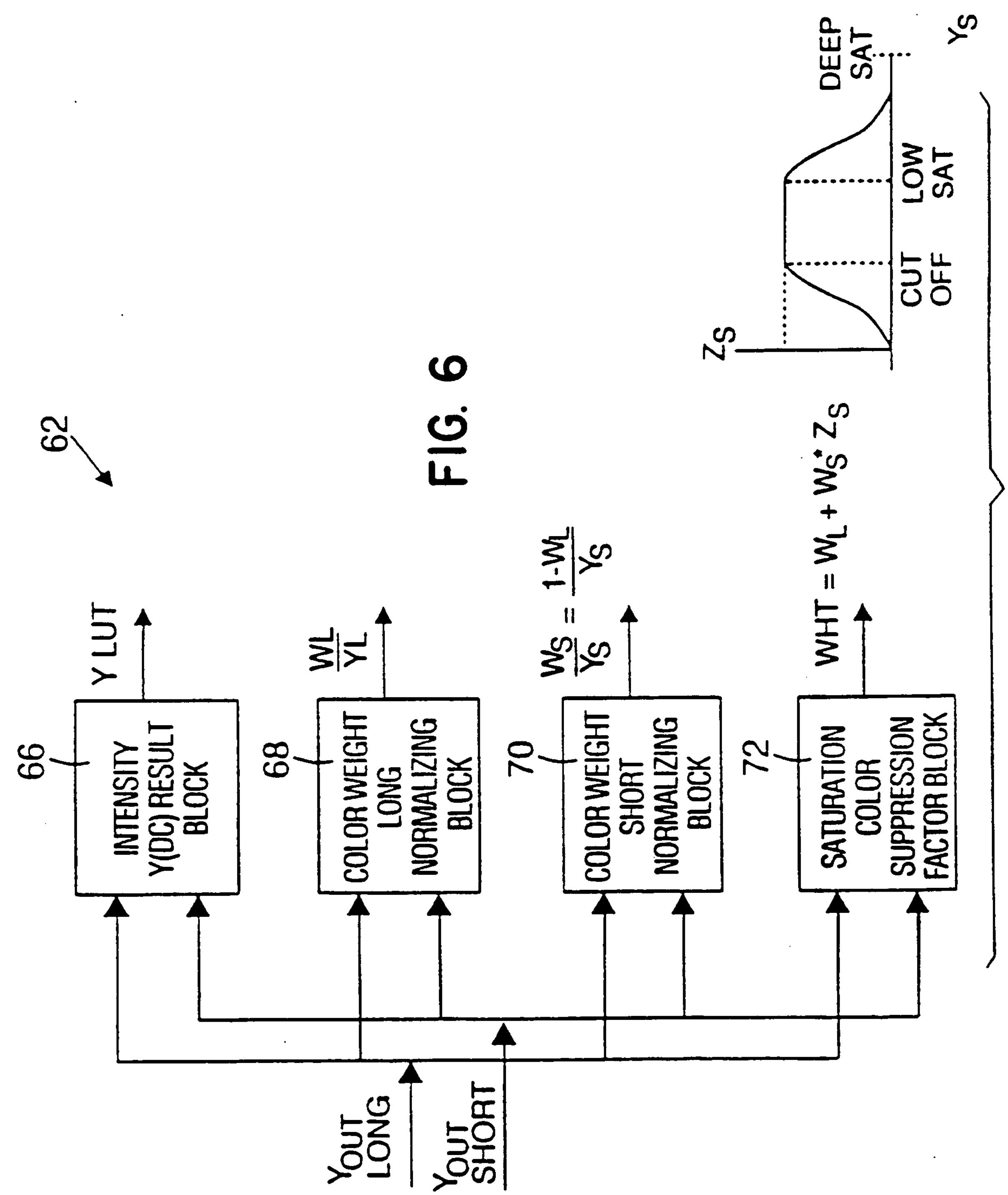

62
66
INTENSITY Y(DC) RESULT BLOCK
Y LUT
68
COLOR WEIGHT LONG NORMALIZING BLOCK
WL/YL
70
COLOR WEIGHT SHORT NORMALIZING BLOCK
$\frac{W_S}{Y_S} = \frac{1-W_L}{Y_S}$
72
SATURATION COLOR SUPPRESSION FACTOR BLOCK
$WHT = W_L + W_S^* Z_S$
Y_{OUT} LONG
Y_{OUT} SHORT
Z_S
CUT OFF
LOW SAT
DEEP SAT
Y_S

FIG. 6

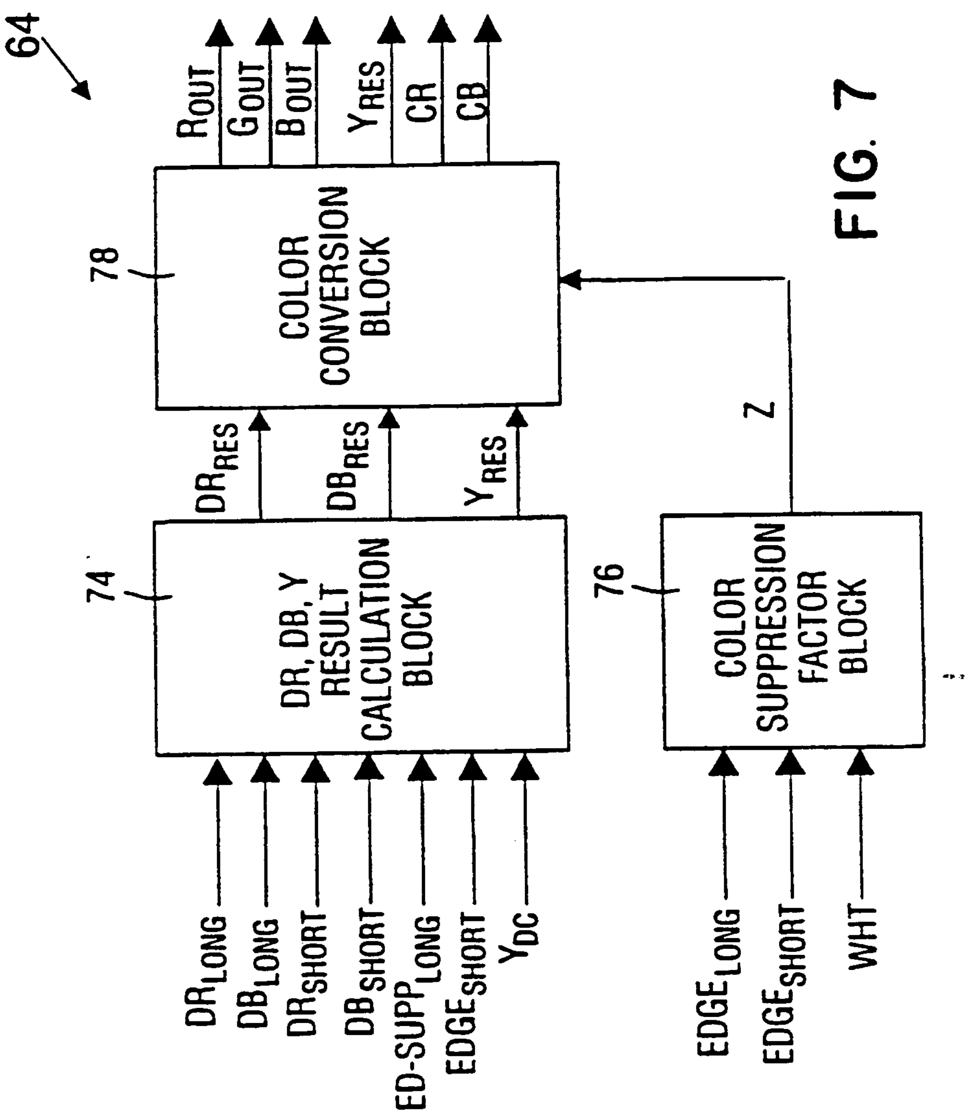

64
78
COLOR CONVERSION BLOCK
R_{OUT}
G_{OUT}
B_{OUT}
Y_{RES}
CR
CB
74
DR, DB, Y RESULT CALCULATION BLOCK
DR_{RES}
DB_{RES}
Y_{RES}
DR_{LONG}
DB_{LONG}
DR_{SHORT}
DB_{SHORT}
$ED\text{-}SUPP_{LONG}$
$EDGE_{SHORT}$
Y_{DC}
76
COLOR SUPPRESSION FACTOR BLOCK
Z
$EDGE_{LONG}$
$EDGE_{SHORT}$
WHT

FIG. 7

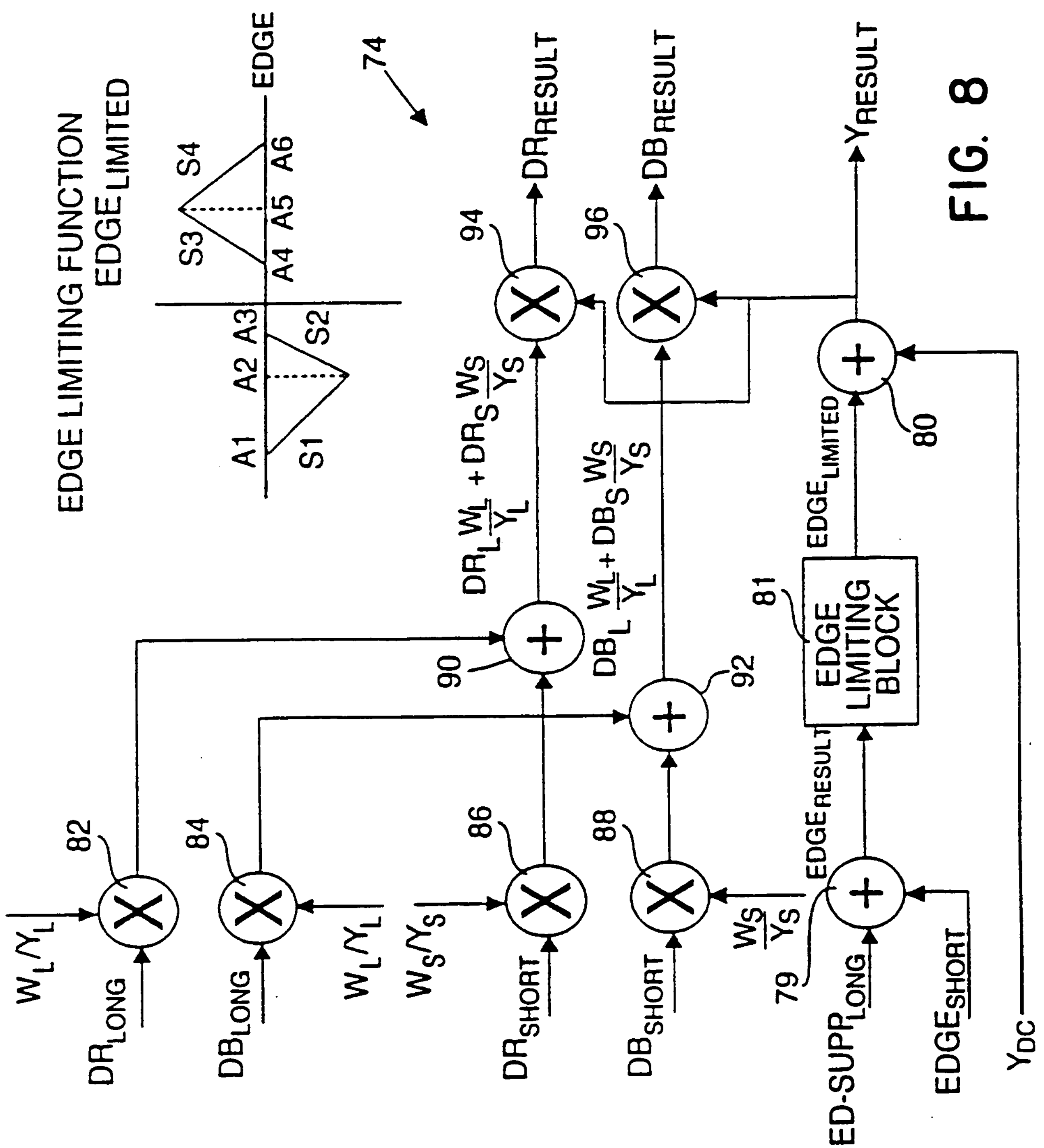

EDGE LIMITING FUNCTION
EDGE LIMITED
EDGE
A1 A2 A3 A4 A5 A6
S1 S2 S3 S4
74
W_L/Y_L
DR_{LONG}
DB_{LONG}
W_S/Y_S
DR_{SHORT}
DB_{SHORT}
$\frac{W_S}{Y_S}$
ED-SUPP LONG
$EDGE_{SHORT}$
Y_{DC}
82
84
86
88
79
$EDGE_{RESULT}$
90
92
81
EDGE LIMITING BLOCK
$EDGE_{LIMITED}$
$DR_L \frac{W_L}{Y_L} + DR_S \frac{W_S}{Y_S}$
$DB_L \frac{W_L}{Y_L} + DB_S \frac{W_S}{Y_S}$
80
94
96
DR_{RESULT}
DB_{RESULT}
Y_{RESULT}

FIG. 8

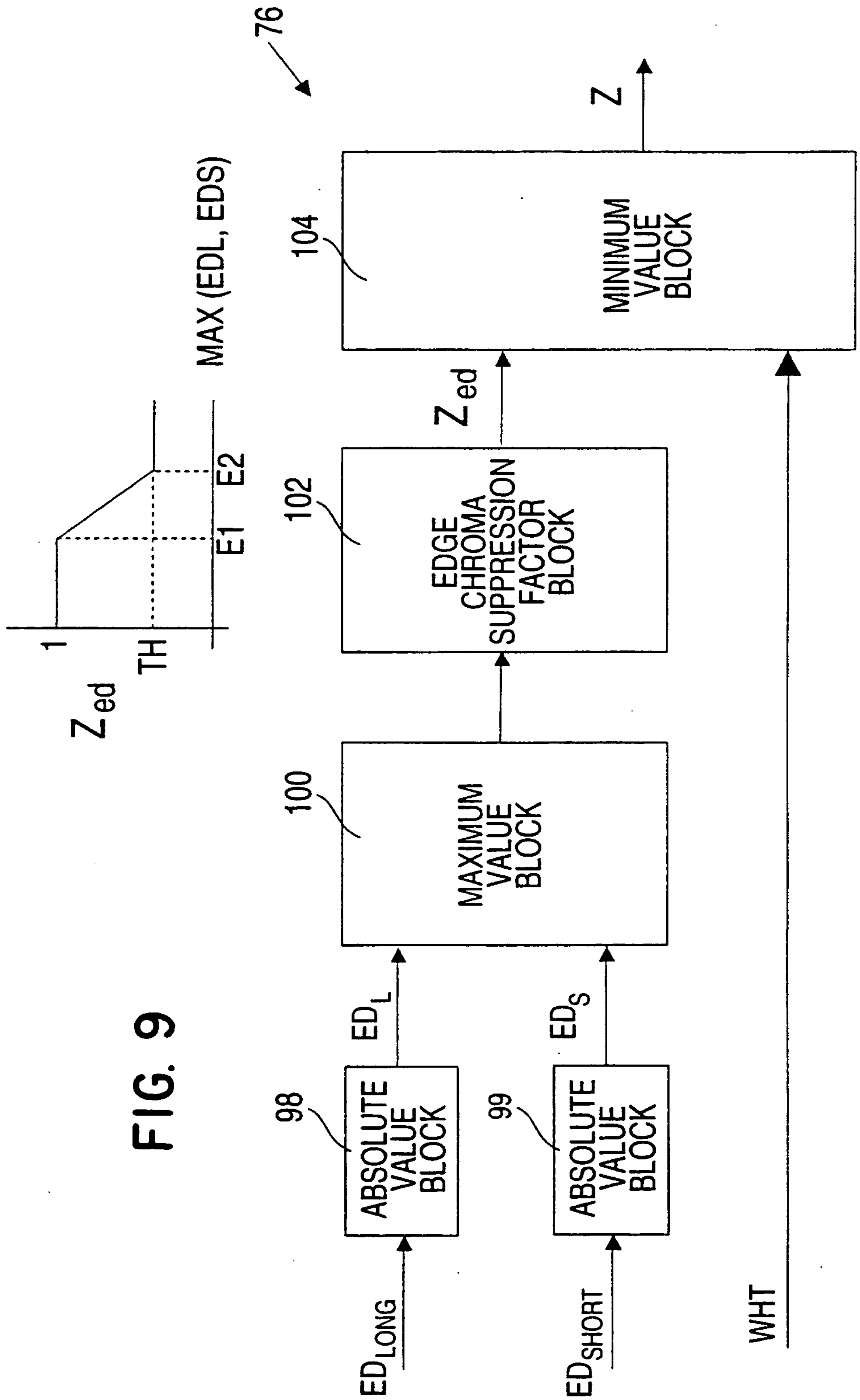

76
ED_{LONG}
ED_{SHORT}
WHT
98
ABSOLUTE VALUE BLOCK
99
ABSOLUTE VALUE BLOCK
ED_L
ED_S
100
MAXIMUM VALUE BLOCK
102
EDGE CHROMA SUPPRESSION FACTOR BLOCK
Z_{ed}
104
MINIMUM VALUE BLOCK
Z
Z_{ed}
1
TH
E1
E2
MAX (EDL, EDS)

FIG. 9

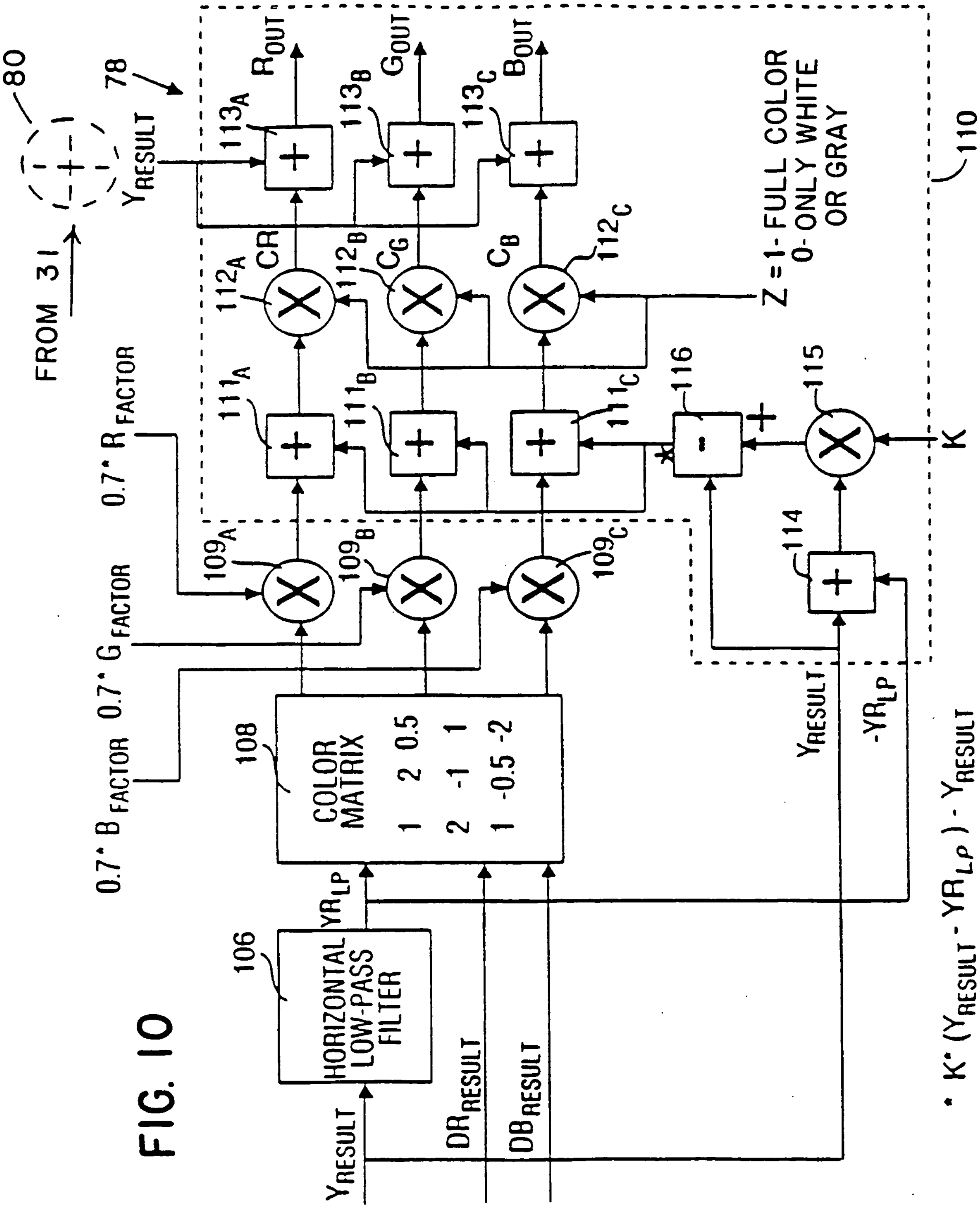
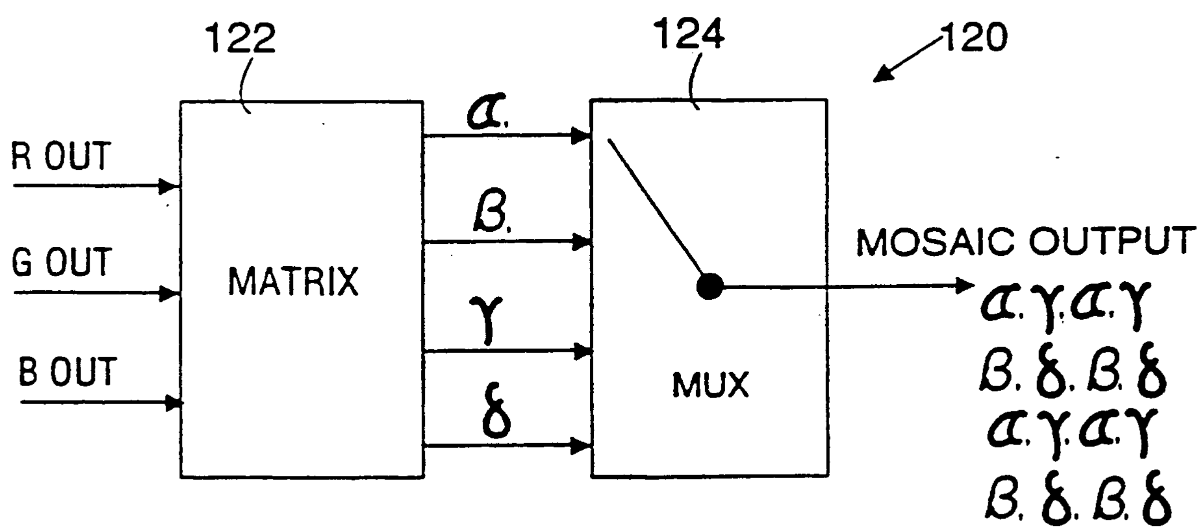

80
FROM 31
78
Y_{RESULT}
R_{OUT}
G_{OUT}
B_{OUT}
113_A
113_B
113_C
CR
C_G
C_B
112_A
112_B
112_C
Z = 1 - FULL COLOR
0 - ONLY WHITE
OR GRAY
110
$0.7 * R_{FACTOR}$
$0.7 * G_{FACTOR}$
$0.7 * B_{FACTOR}$
111_A
111_B
111_C
116
115
K
109_A
109_B
109_C
114
108
COLOR
MATRIX
1 2 0.5
2 -1 1
1 -0.5 -2
106
HORIZONTAL
LOW-PASS
FILTER
YR_{LP}
$-YR_{LP}$
Y_{RESULT}
DR_{RESULT}
DB_{RESULT}
$* K * (Y_{RESULT} - YR_{LP}) - Y_{RESULT}$

FIG. 10



122
124
120
R OUT
G OUT
B OUT
MATRIX
α.
β.
γ
δ
MUX
MOSAIC OUTPUT
α.γ.α.γ
β.δ.β.δ
α.γ.α.γ
β.δ.β.δ

FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US94/01358

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :H04N 9/07, 9/04, 5/228
US CL :348/234, 276, 228, 253
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : H04N 9/07, 9/04, 5/228
348/223, 228, 229, 234, 253, 266, 272, 279, 276, 362, 630

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 4,647,975 (ALSTON et al.) 03 March 1987, Col. 7, lines 49-64, Col. 1, lines 14-16, Col. 4, lines 1 and Col. 6, lines 35-38	1,18,19,20
Y	US, A, 4,614,966 (YUNOKI et al.) 30 September 1986, Figs. 2 and 13	1,4,5,18,19,20
Y	US, A, 4,774,564 (KONISHI) 27 September 1988, see entire document	9,19
A	US, A, 4,584,606 (NAGASAKI) 22 April 1986, see entire document	1-20
A	US, A, 5,138,458 (NAGASAKI et al.) 11 August 1992, see entire document	1-20

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be part of particular relevance
- "E" earlier document published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 March 1994	18 APR 1994

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	James J. Groody for SHERRIE HSIA
Facsimile No. NOT APPLICABLE	Telephone No. (703) 305-4738

Form PCT/ISA/210 (second sheet)(July 1992)★

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A, 4,858,014 (ZEEVI et al.) 15 August 1989 Whole Document	1-20
A	US,A,5,144,442 (GINOSAR et al.) 01 September 1992 Whole Document	1-20
A,P	US, A, 5,247,366 (GINOSAR et al.) 21 September 1993 Whole Document	1-20

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